

# THE ROLE OF TEMPORAL DISCRIMINATIONS IN THE REINFORCEMENT OF SIDMAN AVOIDANCE BEHAVIOR<sup>1</sup>

DOUGLAS ANGER

THE UPJOHN COMPANY

Animals learn to avoid with the Sidman procedure even though the avoidance response is not followed by the termination of any warning stimulus in the environment. What reinforces this response? The accepted explanation has been that the avoidance response is reinforced when it terminates other behavior that has become aversive by pairing with shock. However, the reinforcement may also be derived from the temporal discriminations that develop with Sidman avoidance. These and other temporal discriminations show that the animal has available some events that vary with the postresponse time. The shock will closely follow the temporal stimuli at long postresponse times and would be expected to make them aversive. The stimuli at short postresponse times would have a relatively low aversiveness due to their more remote relation to shock. Since the avoidance response changes a long postresponse time to a short one, that response would be followed by a decrease in aversiveness which would reinforce it. When sharp temporal discriminations are present, reinforcement from the decrease in aversiveness of temporal stimuli probably plays a dominant role in maintaining the avoidance response. This formulation fits the available data and has adequate answers for the objections that have been raised to earlier conceptions of the role temporal discriminations might play in Sidman avoidance. Although under some conditions the reinforcement in Sidman avoidance seems to be primarily due to the decrease in aversiveness of temporal stimuli, under other conditions there probably is reinforcement from the termination of conditioned aversive responses.

The Sidman avoidance procedure, first explicitly investigated by Sidman (1953a, 1953b), has proved to be an exceptionally useful research technique. As Sidman pointed out (1953b), this procedure also has unusual importance because it provides an unequivocal demonstration that animals learn to avoid aversive events without environmental warning stimuli (stimuli preceding the aversive events). Environmental warning stimuli seem to play a major role in avoidance learning when they are present, but the ease of conditioning without them demonstrates clearly that there must be another important source of reinforcement. This paper is concerned with the identification of this reinforcement in Sidman avoidance.

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In Sidman's technique the animal is periodically given brief electric shocks, except that no shock is delivered for a certain time interval after a response in the class specified by the experimenter as the avoidance response. The fixed time-interval between an avoidance response and a shock is called the *response-shock* or  $R^*S^2$  interval, and the fixed interval between shocks when no avoidance response occurs after a shock is called the *shock-shock* or  $S^*S$  interval.

## *Literature on the Reinforcement in Sidman Avoidance*

One view of the reinforcement in Sidman avoidance is based on the fact that with this procedure shocks may closely follow all behavior except the avoidance response, which by definition is never followed by a shock more closely than the  $R^*S$  interval. Thus, Sidman

<sup>2</sup>The notation  $R^*S$  and  $S^*S$  seems preferable to  $R-S$  and  $S-S$  as used by Sidman and others because the hyphen in the latter is easily mistaken for a minus sign. This is especially confusing when the terms are used in an equation where minus signs and  $R-S$  or  $S-S$  are close together. The terms can still be read as before, since the hyphens were not read formerly.

proposed that "the avoidance response is strengthened when it terminates incompatible behavior that has been paired with shock" (1953a, p. 158).

Sidman's interpretation is similar to an earlier analysis by Schoenfeld (1950) of avoidance learning with an external warning-stimulus. Schoenfeld first pointed out that "if the occurrence of an operant response is followed by the removal or reduction of a stimulus associated in the past with a noxious stimulus, the strength of the response will increase" (1950, p. 82). As to the particular stimuli made aversive, he said: "It is proposed that the stimuli removed or escaped by  $R_T$  ( $a_v$ ) [the avoidance response] consist of the proprioceptive and tactile stimuli which together with  $S_1$  [the warning stimulus] form a stimulus compound preceding  $S_2$  [the aversive stimulus]. These proprioceptive and tactile stimuli are produced by the postures and positions of the organism . . ." (1950, p. 87-88; bracketed expressions not present in the original).

Dinsmoor, in his extensive analysis of avoidance and punishment (1954), treated Sidman avoidance behavior in essentially the same way. Strictly speaking, there are differences in terminology among these three formulations. The aversive events are said by Schoenfeld to be "proprioceptive and tactile stimuli" from "postures and positions" (1950, p. 80); by Sidman to be "nonavoidance behavior" (1953b, p. 253); and by Dinsmoor to be the "dependent stimuli" (both in the environment and in the organism) that accompany behavior other than pressing the bar (1954, p. 38). However, each of these analyses derived the reinforcement from the relations between the aversive stimuli and the responses of the animal, so let us use the term *conditioned aversive responses* or *CAR* to describe this group of formulations of the reinforcement in Sidman avoidance. The term *aversive response* is used as an abbreviation for a response when the dependent stimuli that accompany the response (proprioceptive, noises, etc., see Dinsmoor, 1954) have become conditioned aversive stimuli.

Mowrer and Keehn (1958) have proposed another analysis. They pointed out that if "shock be delivered to the subject whenever, let us say, the 20-sec point on the stimulus trace is reached, one would expect that fear

would become conditioned to this point on the trace and, in generalizing forward, would motivate the subject to make the response in question during the intertrial (20-second) interval, thus averting the impending shock. And, since each new occurrence of the response would, so to say, 'reset' the trace, there would be a reduction in fear and hence a reinforcement of the response itself" (Mowrer and Keehn, 1958, p. 215-216).

Sidman (1962a) has recently published data which "led to the suggestion that reduction of shock density be considered an important variable in avoidance behavior" (Sidman, 1962a, p. 247).

These last two formulations both seem to ascribe an important role to temporal discriminations. This paper considers and evaluates the different ways temporal discriminations could play a role in Sidman avoidance and examines some of the problems encountered in this application of temporal discriminations.

#### *Temporal Discrimination Concepts and Terminology*

With food and other positive reinforcement, it has been repeatedly shown under a variety of conditions (e.g. Pavlov, 1927; Skinner, 1938; Anger, 1956; Kelleher, Fry, and Cook, 1959), that differential reinforcement of responses at different times after other events often produces different probabilities of response at those times. Differential response develops even though there is no difference in the environment between the times of high and low response probability. This differential response is similar to a learned discrimination based on environmental stimulus changes; in both cases the reinforced responses increase to a high probability, and the unreinforced responses decline to a low probability. Consequently the term "temporal discrimination" seems appropriate to describe this differential response produced by differential reinforcement at different times after some event. However, the term "discrimination" clearly implies the presence of discriminable events. With temporal discriminations these events would have to be organism differences, that is, differences inside the organism or in its behavior, since there is no difference in the environment between the times of high and low response probabilities. The nature of these organism differences is unknown.

Formulation in discrimination terms seems to be the least hypothetical way to describe temporally correlated responding in terms of known behavior processes. The only serious assumption is the reasonable one that behavior can be conditioned to certain unidentified organism events that change in a consistent way with time. The attempt to describe temporal discriminations entirely without the above assumption, seems to require new behavior processes for which there is far less evidence than there is for the ubiquitous discrimination process and time-related organism events.

Consequently, the viewpoint of this analysis is that animals have available some events, either internal or in their behavior, that change in a consistent way with time after the last response, reinforcement, *etc.* These events function like external stimuli, at least to the extent that differences in responding can be conditioned to these organism differences.

In some cases of temporal discrimination, other behavior has been observed or recorded between the initial event and the deliberately reinforced response. It has been proposed that this collateral behavior, usually called response chains, may have a functional role in the temporal discrimination, *i.e.*, that some temporal discriminations may depend upon such chains (Bruner and Revusky, 1961). Full discussion of the role of response chains in Sidman avoidance is best deferred until after the development of the temporal discrimination analysis. But, in brief, the viewpoint of this analysis is that the temporal stimuli in Sidman avoidance probably result from events not visible in the behavior of the animal rather than from visible response chains. One reason for this view is an almost complete absence of empirical evidence for visible response chains of appreciable length in Sidman avoidance. Another reason is that there seems to be a basic incompatibility between timing based on a chain of responses and any developed explanation of Sidman avoidance responding.

A term is needed to refer to the internal events, whatever they are, that provide the basis for the temporal discrimination. The term "temporal stimuli" will be used. "Stimuli" was chosen because these events seem to function like external discriminative stimuli function, at least to the extent that differences

in responding can be conditioned to these organism events by differential reinforcement. "Temporal" was chosen to distinguish these stimuli from other types of stimuli and because these events are correlated with time measurements. No position is taken as to where these temporal stimuli originate, whether inside or outside the central nervous system *etc.*, except that they do not seem to result from a visible response chain.

Timers do not directly measure the temporal stimuli to which the rat responds nor does the rat react to the laboratory timers. Instead, different response frequencies are observed that are correlated with the time,  $t$ , from some other public event (last response, shock, food reinforcement, *etc.*) (Correlation A in Fig. 1). The consistent relation between the response frequency and timer measurements leads us to infer that the rat has available some events that vary with  $t$  (Correlation C), and that these events enable the animal to produce the different frequencies of response (Correlation B) at different values of  $t$ . It is Correlation C between the unknown events functioning as stimuli and timer measurements that makes it reasonable to label these different unknown stimuli with the correlated timer measurement of  $t$ . This is what we do when we talk about the response to the stimulus of 8 sec after the last response or 8-sec *postresponse time* (8-sec *PRT*). For example, it is observed that when the timer reads about 8 sec after the subject has responded, the response probability is different than when the timer reads about 4 sec after the last response; hence something must be different within the organism. Whatever the stimulus is at 4 sec, it will be called the 4-sec *PRT* stimulus to distinguish it from the different stimulus at 8 sec, the 8-sec *PRT* stimulus. Thus, the objectively-measured time intervals label the inferred events correlated with them.

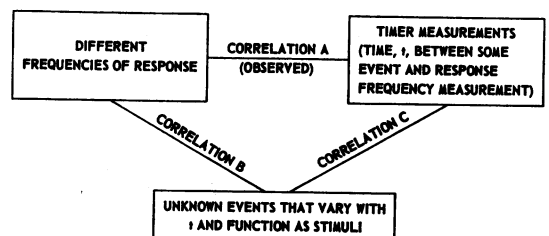


Fig. 1. Diagram of the relations between responding, time measurements, and temporal stimuli.

To summarize the preliminary considerations: (1) Avoidance develops without any external stimulus paired with the aversive events. (2) The reinforcement of this Sidman avoidance can be derived from the pairing of the aversive events with responses (CAR). (3) It is practical to describe and analyze the roles played by temporal discriminations without specifying the nature of the underlying events. Next, three somewhat different ways temporal discriminations may play a role in the reinforcement of Sidman avoidance behavior will be considered: (1) via conditioned aversive temporal stimuli, (2) via omission of a member of a periodic sequence, and (3) via changes of shock frequency.

#### REINFORCEMENT OF SIDMAN AVOIDANCE DERIVED FROM TEMPORAL DISCRIMINATIONS

##### *Possibility 1, Conditioned Aversive Temporal Stimuli (CATS)*

It would be expected that temporal stimuli preceding aversive stimuli would become conditioned aversive stimuli. This basic idea has been mentioned by Mowrer and Keehn (1958). However, there seem to be substantial advantages to the general type of formulation employed by Keller and Schoenfeld (1950), Schoenfeld (1950), Skinner (1953), Dinsmoor (1954), and others. Thus the term "aversive stimulus" will be used to refer to those stimuli for which it has been shown that the reduction or elimination of the stimulus reinforces the preceding behavior (increases its frequency). As the aforementioned investigators have pointed out, it is well established that when a neutral stimulus precedes or accompanies an aversive stimulus, the neutral stimulus acquires the aversive property; it becomes aversive too, a conditioned aversive stimulus.

This aversive-stimulus formulation does not mention the "fear reaction" to which Mowrer and others refer; instead, it speaks of the acquisition of an aversive property by a stimulus. When a noise stimulus preceding an electric shock is said to have acquired an aversive property, this certainly does not refer to any change in the acoustic events in the environment of the animal. Instead, the "acquisition of an aversive property" refers to a change in the reaction of the animal to the

noise. Then why not call this new reaction a "fear reaction"? Because "aversive property" refers to just one part of a complex reaction, a precisely defined part. The whole reaction to a conditioned aversive stimulus is an extraordinarily complex reaction with many different components (e.g. Lindsley, 1951; Davis, 1957; Martin, 1961; Simon, 1961), many of which are difficult to measure. Although the different components interact and affect one another in complex ways, still they have enough independence to allow considerable variation in their relative magnitudes as changes are made in the nature of the aversive stimulus, the intensity and duration of the aversive stimulus, the recent treatment and past history of the organism, the individual organism, species, etc. Consequently, there is not just one reaction to a conditioned aversive stimulus, nor even a single graded series of reactions; instead, there is a tremendous variety of reactions with boundaries from other emotional reactions that are not yet distinct or well defined.

In operant experiments there is seldom any measurement of the many physiological changes produced by aversive stimuli, to say nothing of estimation of the pattern of several physiological changes. On the other hand, there is usually ample evidence, either from the experiment or from the literature, that the stimuli labeled as conditioned aversive stimuli do satisfy the criteria for that term, namely, that either their termination reinforces or that they have been paired with a stimulus whose termination reinforces. If this information is not already available, then it is usually easy to obtain. Consequently, the term "conditioned aversive stimulus" is precisely defined and its applicability easily determined. In operant studies there is seldom need for risky assumptions about unmeasured physiological changes since such assumptions are seldom utilized in the subsequent analysis. Instead, it is the properties of an aversive stimulus that are usually important for subsequent analysis, namely, the ability of the stimulus to condition operant responses by its termination and to make other stimuli aversive by temporal pairing.

This is not to imply that behavior research will not profit from the investigation and measurement of the physiological effects of conditioned aversive stimuli. Other effects of

these stimuli are not only interesting in their own right but may have different interactions with behavior that may prove to be of considerable importance.

Now let us apply the concepts of conditioned aversive stimuli and temporal stimuli to Sidman avoidance. Just as an external stimulus preceding a shock becomes a conditioned aversive stimulus and reinforces responses which terminate it, so may temporal stimuli preceding shocks become conditioned aversive stimuli, and may reinforce responses which terminate them. At the start of Sidman conditioning, the constant  $S^*S$  interval results in the consistent occurrence of shocks at certain times following the last shock. Consequently, the temporal stimuli occurring at these times, the stimuli at *postshock times*, *PSTs*, just short of  $S^*S$  would presumably become highly aversive. The temporal stimuli at the *PSTs* soon after a shock would develop the least aversiveness since they would have a backward conditioning relation to the shock they follow. Most of the literature indicates that backward conditioning is either of little importance (Kimble, 1961) or has an effect opposite to that of forward conditioning (Barlow, 1956). These temporal stimuli after a shock would have the most remote forward conditioning relation to the next shock of any *PST* stimuli. Therefore, the *PST* stimuli soon after a shock would probably be the least aversive. Other *PST* stimuli would be intermediate in aversiveness according to the time between their occurrence and the shock. To clarify this analysis, Fig. 2A presents a rough estimate of how the relative aversiveness would be expected to change when no avoidance response occurs. (Figure 2 is diagrammatic; no claim is made for the specific curves or for any properties other than the ones discussed in the text.) Figure 2A is a curve of the relative aversiveness due to all sources, so a large additional aversiveness due to the shock is indicated at  $PST = S^*S$ . The occurrence of a shock changes the *PST* to zero (by the definition of *PST*), so until an avoidance response occurs, the animal is not exposed to stimuli at *PSTs* longer than  $S^*S$ . Eventually, during the  $S^*S$  interval, the animal makes the response selected as the avoidance response with the result that no shock occurs at  $PST = S^*S$ , and the animal does encounter stimuli for *PSTs* longer than  $S^*S$ . Since stimuli at *PSTs*

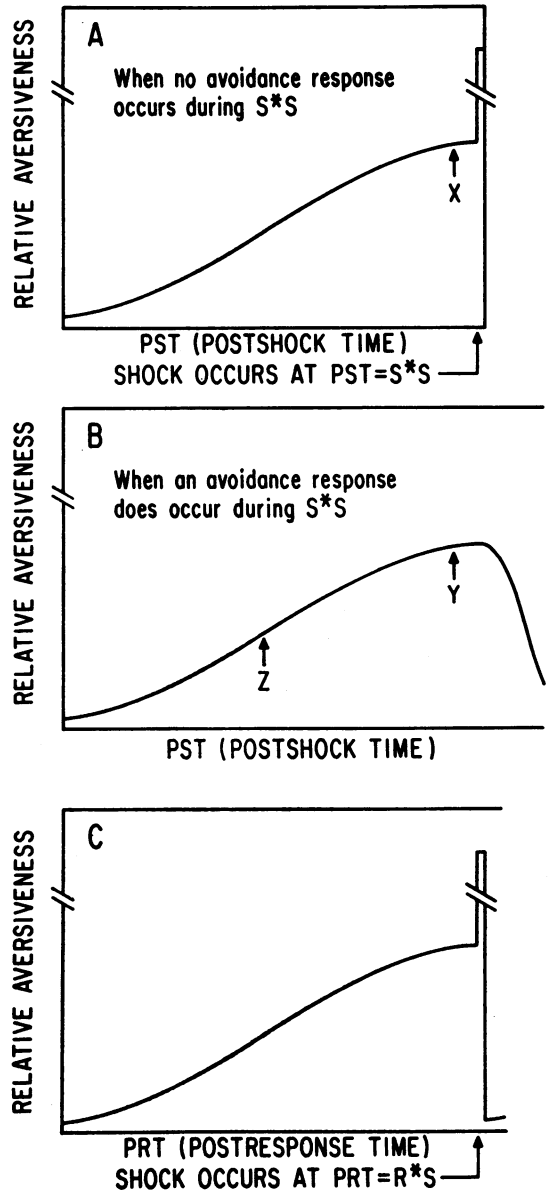


Fig. 2. Estimate of probable changes in relative aversiveness of temporal stimuli at different times after a shock (A and B) and at different times after a response (C). In the well-trained animal, a shock shifts the animal to the start of curve A, and a response shifts the animal to the start of curve C. Curve B is only relevant before Curve C is learned.

longer than  $S^*S$  have never been paired with shock, they are aversive primarily by generalization from stimuli at shorter *PSTs* and their aversiveness probably will decline somewhat as suggested in Fig. 2B. Thus, the aversiveness of the temporal stimuli increases with the

length of the PST to a maximum with the stimuli at  $PST = S^*S$  and then declines at longer PSTs. Since no shock follows an avoidance response, the high aversiveness from the shock is absent in Fig. 2B. If the magnitude of a rat's motor reaction to a mild shock has a moderate correlation with the conditioned aversiveness of the current stimuli, then some evidence for the general type of aversiveness curve described above can be found in the data of Brown (1939). He gave periodic shocks, 12 sec apart, and then tested the rat's motor reaction to another test shock at various times. The motor response increased with time after the shock up to a maximum at the time when the shock usually came (12 sec), but then decreased sharply at a longer time interval (15 sec).

When by chance an avoidance response is made just before the time when the shock has been occurring, e.g. at Y in Fig. 2B, then a shock does not occur at  $PST = S^*S$ .<sup>3</sup> Instead, the avoidance response is followed by a decrease in the aversiveness of temporal stimuli; this decrease should reinforce the response. When a response is made at an earlier PST, e.g. at Z in Fig. 2B, the reinforcing effect will be less. This results partly because there will be a longer delay between the response and the decrease in aversiveness, and partly because the response will be followed for a longer period by aversiveness from conditioned aversive temporal stimuli. Still, there might be a rather wide range over which there would be some net reinforcing effect. This reinforcement will be called *PST reinforcement* (because it derives from the PST aversiveness curve) to distinguish it from two slightly different types of reinforcement by temporal stimuli. Notice that "PST" is used to refer to the time since the last shock irrespective of whether an avoidance response occurs or not. "PRT" will be used to refer to the time since the last avoidance response irrespective of whether a shock occurs or not.

How do the events following an avoidance response differ from the events following a nonavoidance response? After an avoidance response at time Y, the curve of Fig. 2B results. After a nonavoidance response at the

same PST (without any avoidance response during that  $S^*S$ ), i.e. at X, the curve of Fig. 2A results. After the avoidance response, there is a decrease in aversiveness. After the nonavoidance response there is a big increase in aversiveness before there is any decrease. It would be expected that the big increase in aversiveness after the nonavoidance response at X would at least greatly reduce, if not eliminate, the effect of the following decrease. Thus there would be much less reinforcing effect, if any, on the nonavoidance response. Consequently the avoidance response is selectively reinforced. When the aversiveness is high, only the avoidance response is consistently followed by a decrease in aversiveness. The fact that nonavoidance responses are followed by shock eliminates or reduces their reinforcement, but it is not necessary that all other responses be made aversive (or that any other responses be made aversive) to reinforce the avoidance response. This emphasizes the difference from the CAR analysis and also fits the observation that a few animals learn Sidman avoidance after surprisingly few shocks (Sidman, 1962a, p. 247). Results at our laboratory confirm this observation.

As soon as responding begins, there develops another change in aversiveness following a response. Once responding begins, shocks consistently and closely follow certain times after the last avoidance response. Consequently, the temporal stimuli occurring at those PRTs just short of  $R^*S$  should become highly aversive. The temporal stimuli at short PRTs would be the least aversive due to the much greater time between their occurrence and that of the shock. At intermediate PRTs the stimuli would have intermediate aversiveness. Thus, the aversiveness of a PRT stimulus would be expected to increase with the PRT from lowest aversiveness at the time of the response to highest at  $PRT = R^*S$ , as shown in Fig. 2C. Since aversiveness is lowest at and right after a response, all responses except those at very short PRTs would reduce aversiveness, and would be reinforced by that decrease. The greater the PRT preceding the response (up to the shock), the greater the decrease in aversiveness, and therefore the greater the reinforcement. This reinforcement will be called *PRT reinforcement* since it is derived from the PRT aversiveness curve.

<sup>3</sup>Ordinarily  $R^*S$  is greater than or equal to  $S^*S$ , and that is assumed throughout this paper. When  $R^*S$  is much less than  $S^*S$  the situation changes greatly; that situation will be analyzed elsewhere.

The positive slopes to the left of the maximum in Fig. 2A, B, and C probably result from some combination of three factors. They are (1) partly due to stimulus generalization, but (2) partly due to the occurrence of shock following all PRT and PST stimuli, though at widely different delays. Long PRT stimuli are closely followed by shocks, medium PRT stimuli are followed by shocks after a delay, and short PRT stimuli are followed by shocks only after a long delay. In Fig. 2C the positive slope is also (3) partly due to the greater extinction of the aversiveness of short PRT stimuli, because there are many more exposures to short PRTs than to long ones (discussed in more detail later). As in avoidance with an external warning stimulus, each exposure to the conditioned aversive stimulus without a shock probably extinguishes its aversiveness somewhat.

The negative slope to the right of the maximum seems to be due primarily to stimulus generalization, because the PSTs greater than S\*S are never paired with the shock at PST = S\*S. For this reason an asymmetrical curve was drawn in Fig. 2B.

PST reinforcement results from the postshock temporal discrimination established by the S\*S interval. PRT reinforcement results from the postresponse temporal discrimination established by the R\*S interval. But there are further differences. In PRT reinforcement with a well developed PRT discrimination, a response quickly reduces the aversiveness to its lowest value. The longer the PRT at the time of response, the greater will be the reduction, but irrespective of the magnitude of the reduction, it would be fast and to the lowest aversiveness. However, PRT reinforcement cannot operate until the animal has responded, and has received shocks correlated with certain PRTs and not with others; *i.e.* has developed the postresponse discrimination shown in Fig. 2C. In contrast, PST reinforcement, based on the postshock discrimination, does not involve as fast a reduction in aversiveness, but it can reinforce the first response if there have been enough shocks to develop the PST relative-aversiveness curve shown in Fig. 2A. In PST reinforcement, aversiveness does not decrease as rapidly because there is no decline until PST equals S\*S. Depending on the PST when the subject responds, the aversiveness will increase either to a minor

or a major degree before it declines after the PST equal to S\*S. Even after PST equals S\*S the rate of decline of aversiveness will probably be slower than after a response, due to generalization. In spite of these shortcomings, the PST reinforcement may play a role in reinforcing the first few responses until the PRT discrimination develops.

There is one more situation to examine, one which seems to produce a conflict between the PST and PRT conditioning. Consider the situation when (1) the PRT curve of aversiveness has been learned, (2) a shock occurs, and then (3) a response occurs, say half-way through the S\*S interval (at Z in Fig. 2B). The PST reinforcement calls for an increase in aversiveness according to Fig. 2B. But the PRT reinforcement calls for an immediate decrease in aversiveness according to the curve of Fig. 2C (at PRT = 0). This conflict is easily resolved by consideration of when the shocks actually occur and what the rat has learned. Before the rat has learned the curve of Fig. 2C, the aversiveness following a response-after-a-shock will be determined by the curve of Fig. 2B, producing PST reinforcement. But after the rat learns the postresponse aversiveness curve of 2C, then the curve of 2C will describe the aversiveness changes following a response-after-a-shock. This results because the shocks occur at the same time after that response as after other responses, consequently the aversiveness curve should eventually be approximately the same as after other responses. In other words, in this situation the R\*S timer, not the S\*S, determines the shocks. This reinforcement will be called *PST plus PRT reinforcement*. It is similar to PRT reinforcement, and differs only in that the aversiveness before the response is determined by the PST because the S\*S timer is controlling shocks then; the aversiveness after the response is controlled by the PRT because the R\*S timer is programming shocks then. In PRT reinforcement the aversiveness is controlled by the PRT both before and after the response because the R\*S timer is controlling the shocks before and after. In PST reinforcement the aversiveness is controlled by the PST both before and after the response, because the rat has not yet encountered the lack of shocks following a response, *i.e.*, the rat has not yet learned the Fig. 2C curve of aversiveness following a response. The PST plus PRT rein-

forcement provides a fast reduction of postshock aversiveness after an avoidance response, whereas PST reinforcement gives a slower reduction of postshock aversiveness after an avoidance response, and PRT reinforcement gives a fast reduction of the postresponse aversiveness after an avoidance response.

The PST reinforcement has the shortcomings already pointed out and it is entirely replaced by the other sources of reinforcement before long. Still, it may play some role in strengthening the first avoidance responses until the PRT discrimination develops and provides a prompt decrease in aversiveness following a response. In cases of fast conditioning of Sidman avoidance this may be operating. But the PST reinforcement would not be essential for conditioning. Especially when conditioning is slow, the PRT aversiveness curve may develop before the PST reinforcement has any appreciable effect. An initial operant level of response tendency (of unspecified origin) is necessary for the first response with avoidance conditioning as well as with food reinforcement. There seems to be no reason why this initial response tendency cannot produce several responses from which the PRT aversiveness curve is learned enough so that further responses are facilitated by the PRT reinforcement and the PST plus PRT reinforcement, and so responding progressively increases in frequency. Then the PRT with the PST plus PRT reinforcement would do all the conditioning and the PST reinforcement would be of little or no consequence. The PST reinforcement is *not essential* for the main viewpoint presented here; at most it is an ephemeral phenomenon during conditioning. With a variable  $S^*S$  interval one should be able to eliminate PST reinforcement, but that should not eliminate conditioning or maintenance of Sidman avoidance under favorable conditions, though conditioning might under some conditions become somewhat more difficult. The primary basis of the conditioned aversive temporal stimuli (CATS) reinforcement lies in the PRT, and PST plus PRT reinforcement, *i.e.*, in the low aversiveness of the temporal stimuli following an avoidance response. The low aversiveness at this time results in a decrease in aversiveness following the avoidance response.

Could the temporal stimuli discussed here actually be the proprioceptive, *etc.* stimuli

specified by Schoenfeld, Sidman, and Dinsmoor, so that their CAR formulation is not basically different from the one presented here? Both formulations do propose that certain stimuli are made aversive by pairing with shock, and that the termination of these stimuli reinforces the avoidance response. However, there is a distinct difference in the nature of the conditioned stimuli specified. The essential property of the conditioned aversive temporal stimuli or CATS is their difference at different PRTs or PSTs, and their equivalence at the same PRTs or PSTs. The essential property of the CAR stimuli specified by Sidman, Schoenfeld, and Dinsmoor is their production by all other responses besides the avoidance response. Without a high correlation between these non-avoidance-responses and the temporal stimuli (such a correlation has not been proposed in connection with the CAR viewpoint), these two classes of events change differently and independently of each other. The animal makes different responses at the same PRT and makes the same responses at different PRTs. Consequently non-avoidance-responses and the temporal stimuli represent two different classes of events to which the reinforcement may be related. The differences at different PRTs and PSTs are of central importance in the CATS formulation, and have not played a role in the CAR formulation.

There is one point of slight overlap between the two formulations. Both view the avoidance response as the least aversive event. From the CAR point of view, it is the only non-aversive event. From the CATS point of view, the avoidance response, or PRT equal to zero, is the least aversive event, although short PRTs have nearly as low aversiveness, and consequently are of considerable importance. With a moderate  $R^*S$  and a good temporal discrimination, the many seconds of low-aversive PRT stimulation may turn out to be more important in the reinforcement of the avoidance response than the brief time involved in pressing the bar. Thus, the CAR and CATS formulations differ both as to what events are aversive and what events are relatively non-aversive, though they do agree that the avoidance response is as low as any event in aversiveness.

The CATS formulation can provide the reinforcement in other avoidance procedures



where the warning stimulus is not terminated by the avoidance response, such as trace conditioning (brief warning-stimulus plus a time interval before shock), delayed conditioning (long warning-stimulus), and delayed termination of the warning stimulus (Verhave, 1959). The CATS viewpoint also fits the delay of the response seen in trace conditioning (Kamin, 1954) and delayed conditioning (Brush, Brush, and Solomon, 1955).

#### *Possibility 2, Omission*

It is well established that termination of an aversive stimulus after a response will reinforce that response. Consider such escape conditioning where each response eliminates any electrical shock for 30 sec, then a continuous shock begins again, and continues until the next response. Shock is usually considered a continuous event, but in most equipment the animal receives a group of separate pulses. The shock is interrupted by the switching of a grid scrambler, by the rat jumping about, as well as by the alternation of the 60 cycle AC source. Suppose the spacing between these pulses is increased, first to .5 sec, then to 1 sec, 2.5 sec, *etc.* At what frequency of shock pulses does the conditioning cease to be escape conditioning and become Sidman avoidance conditioning? It seems doubtful that escape from 4 shocks per sec is basically much different from escape from continuous shock. Does a basic difference develop before shocks are spaced at 2.5-sec intervals, an interval that has been used for Sidman avoidance (Sidman 1953b)? There seems to be a continuum between the usual continuous shock and a periodic shock. The termination of a periodic sequence of shocks is similar to the termination of the usual continuous shock, and the omission of members of a periodic sequence of shocks is similar to the interruption of the usual continuous shock. These similarities of periodic and the usual continuous shock increase as the time between shocks is shortened. In view of this continuum, and the known reinforcing properties of the termination of an aversive stimulus, it seems that the question is not whether the omission of members of a periodic sequence of shocks is reinforcing, but rather over what range of periodicities is there a reinforcing effect from omission of members of a periodic shock sequence. As the intershock time is increased, the ability

of the animal to detect sequence interruptions must decrease, and eventually fail (*e.g.* at least at intervals measured in days). But in view of the ease with which rats develop temporal discriminations, such discriminations may extend the detection of sequence interruptions out to intershock times of 20 sec or more. It seems relevant that people easily learn certain temporal discriminations. The first time one hears a new church bell with an unknown period, one does not have to wait long after the third sound to know it is three o'clock, not four o'clock.

The above analysis is a special case of the following more general formulation. When a member of a periodic shock sequence is omitted following an avoidance response, then the temporal stimuli that previously were paired with the shock now occur without the shock. This omission of shocks from a compound of some other stimulus with shock may be a more general concept than omission of members of a periodic shock sequence, and might provide reinforcement. This view also includes avoidance with an external warning stimulus, since there an avoidance response during the warning stimulus causes the warning stimulus to be unaccompanied by the shock that otherwise follows it. From this viewpoint the warning stimuli in classical avoidance just replace the temporal stimuli (or just augment them if the warning stimuli are periodic). The ability of animals to discriminate between stimulus compounds and their individual members was shown by Woodbury (1943). With both temporal and external warning stimuli, the avoidance response may be reinforced by the following elimination of the pairing between certain stimuli and shock. Such termination or elimination of an aversive stimulus from its conjunction with another stimulus is enough similar to the termination of an aversive event, that the termination of the conjunction may be reinforcing too.

The above discussion of the omission possibility of reinforcement in Sidman avoidance was based on the interruption of the periodicity of the S\*S interval. Does such reinforcement persist after continued training when S\*S intervals occur most infrequently, often less than once a day? In this laboratory a rat has maintained a high rate of response for 69 days (21½ hr daily for a total of 172 hr) without any occurrence of an S\*S interval.

Monkeys probably would go longer. When the S\*S periodicity is so rarely received by the animal, it is hard to believe that its continual interruption plays a major role in the maintenance of the avoidance response. Elimination of shocks delivered by the R\*S timer produces a decline in responding in a much shorter period of time. Even if continual interruption does play a major role, how is that interruption focused on the avoidance response rather than on other responses that occur during the long periods without S\*S intervals? Thus, the omission view seems to require tenuous *ad hoc* assumptions to describe well-developed Sidman avoidance behavior. In contrast, the CATS and CAR theories handle this situation easily. For the CATS theory, when shocks are few, the shocks maintain the aversiveness of PRT stimuli, and the avoidance response is reinforced by the decreases in aversiveness which occur after most of the avoidance responses. The animal is rarely exposed to PST stimuli, so shocks following shocks are rarely necessary to maintain the aversiveness of PST stimuli. In fact, if PST exposures are low enough, it might even be possible (especially in monkeys) to maintain the aversiveness of PST stimuli enough by generalization from aversive PRT stimuli so that shocks following shocks can be eliminated altogether.

Would the omission type of analysis work in this situation if it were based on the R\*S interval that seems to dominate the behavior at advanced stages of training? Such analysis also encounters difficulties. Consider an animal on a 20-sec R\*S. Say a response occurs 16 sec after the previous response. This response resets the PRT to zero. To specify stimuli that have been associated with shock and that occur without the shock after an avoidance response, it must be assumed that the animal detects the fact that 20-sec-after-the-second-back-response occurs without an associated shock. Sometimes several responses would intervene before 20 sec after a particular response. Apparently the animal would have to be able to time from several different responses simultaneously. These seem dangerous hypotheses to make at present, especially when the alternative CATS formulation lacks this problem. However, such behavior is not inconceivable and this possibility should not be altogether forgotten. The omission formu-

lation also encounters trouble with a variable S\*S interval or a variable R\*S interval (Sidman and Boren, 1957; Dinsmoor, 1962) which will be considered later. Thus, with our present knowledge the omission possibility does not seem to provide the best explanation for the well-developed Sidman avoidance response (with few shocks following shocks). However, the omission possibility could be important in getting the avoidance response started during conditioning when the shocks are periodic and their frequency is high, even though omission may be of minor importance later.

### *Possibility 3. Other Effects of a Decrease in the Rate of Aversive Events*

Two interpretations can be made of the proposal that a response is reinforced by a decrease in shock frequency. (a) The proposal can be construed as a generalization that describes results with several procedures but avoids specification of how the change in shock frequency is detected by the animal. (b) The proposal can also be construed as a suggestion that the animal detects a change in shock frequency in some way other than those specified already, possibly a more direct detection. Let us consider these two approaches separately.

*Possibility 3a. Decrease in shock rate without specification of how the decrease affects the animal.* The statement that responses are reinforced by a decrease in shock frequency does constitute an empirical generalization since it will encompass the results of several different procedures. This statement is not confined to only what is done and directly observed with one procedure as is the case with a statement such as "a response is reinforced when periodic shocks are delayed a fixed time-interval after the response." But this statement does not specify how the decrease in shock frequency makes contact with the animal, and consequently it leaves unanswered a major and basic question. The CAR and CATS formulations do specify what the rat detects in terms of processes well established by other experimentation. It seems undesirable to retreat from formulations with more complete specification as long as they are able to handle the experimental data. The shock-frequency-decrease formulation is not immune to test, even though it does not specify the method of detection. Peculiarities

of the CAR and CATS processes may make it possible to maintain an avoidance response that does not decrease the shock rate.

*Possibility 3b. Decrease in shock rate detected in some other way.* In a sense, all the preceding analyses, the CAR, CATS, and especially the omission analysis, could be considered ways that a shock-frequency-decrease may be detected by the animal. It seems important to distinguish these different ways; hence, the labels already defined will be used for the already considered formulations, and it will now be examined whether some other way should be considered. The presence of an alternative has been investigated by application to available data and by experiment. Both investigations have encountered serious unsolved difficulties.

There is evidence that rats are affected by small differences in the frequency of food reinforcement. For example, Anger (1954, 1956) found that with VI food reinforcement, rats generate different probabilities of response at different PRTs. The different response probabilities seemed to be dependent on differences in the rates of reinforcement of the responses at the different PRTs. It would appear much easier for the animal to react to changes in the rate of shocks than to react to the different rates of food reinforcement associated with different PRTs during the same time period. Stein, Sidman, and Brady (1958) have published evidence that rats are influenced by rather small reductions in the average VI food rate occasioned by decreased responding in the conditioned-suppression situation. The reinforcements were not periodic, but were spaced at variable intervals, so an interpretation in terms of temporal stimuli as in the omission possibility does not seem practical.

Could a similar influence of decreases in the shock rate be basic to the reinforcement in Sidman avoidance? This leaves the manner of influence vague, but it does seem reasonable that such changes could affect the animal. However, difficulties arise in specifying how the change in shock rate could selectively reinforce one particular response. In this regard the avoidance situation differs considerably from the food reinforcement situation. Each food reinforcement is more closely paired with one particular response than with other responses, so the selective action of the rein-

forcements on that response is reasonable. In the avoidance situation the shocks are not paired with the avoidance response, so pairing of shock and response cannot be the basis of the selective action on the avoidance response. The alternative is that it is the decrease in shock rate that is correlated in time with the avoidance response. But when does the decrease in shock rate occur? With a periodic shock, when the period is lengthened the decrease in shock rate could be said to occur at the time when a shock formerly occurred but now fails to occur. But that is omission (Possibility 2) already considered. Essentially, the omission possibility uses temporal stimuli to detect changes in the intervals between periodic shocks, while the CATS possibility uses temporal stimuli to detect differences in shock frequency at different PRTs and PSTs. How else can a shock frequency change be sharply enough localized in time to focus its effect on some particular response?

The problem of detection of the change in shock rate becomes more acute when a variable S\*S interval is used and also when Sidman avoidance behavior is well learned. First consider initial conditioning with a variable S\*S interval. A variable S\*S interval makes it still more difficult to specify when a shock-rate decrease occurs, and consequently more difficult to pair the decrease with a particular response (unless the rate-change produced by a response is great). With variable intervals between shocks, a change in shock rate amounts to a change in the distribution of *intershock times*, (*ISTs*). If there is overlap in the IST distributions before and after the change, then several shock intervals may be necessary to establish that a rate change has occurred. It is true that even when one response does not change the IST distribution much, a group of responses spread out in time will make still longer ISTs that may be quite different. However, there still remain the unsolved problems of when the change in shock frequency occurs, and how it is focused on a group of responses spread out over an appreciable time period and often mixed with various other responses.

The problem of the detection of a change in shock frequency also is more difficult when the maintenance of well-developed Sidman avoidance is considered. After extensive training, the frequency of shocks often becomes

quite low and stable. The shocks occur at variable intervals, but the distribution of these ISTs stabilizes. Where are the changes in shock rate, or IST distribution that maintain the responding then? As mentioned earlier, shocks following shocks timed by the S\*S timer often average less than one per day, and one rat has gone 69 days without any. It is hard to believe that under these conditions the rare cases of change in shock rate following S\*S intervals play the major role in maintaining the high response rates. In contrast, the CAR and CATS formulations provide reinforcement by a decrease in aversiveness following a large proportion of the responses, and the S\*S intervals play a very minor role.

The data indicate that variable S\*S intervals give rats surprisingly little trouble. Boren and Sidman (1957) investigated the intermittent delivery of shocks assigned by a Sidman schedule. With the sequence of omitted shocks randomized, the animal received a variable S\*S interval as well as a variable R\*S. Because the nominal S\*S and R\*S were equal, there probably was overlap between the distribution of ISTs with and without responding. Important changes in the behavior were not found until below 30% shock delivery, and some animals were little affected down to 10%. The authors reported that due to the high response rates and consequent lack of long IRTs (interresponse times), the animals probably received few R\*S longer than 20 sec. How many long S\*S were received was not mentioned. In any case a remarkable insensitivity was found to considerable reduction in the delivery of shocks during the periods of non-response.

Dinsmoor (1962) studied a modification of Sidman avoidance with a variable S\*S. His "no signal" control group essentially received a variable S\*S, and a response sometimes (VI schedule) delayed the shock. The R\*S was somewhat variable too. As the avoidance response was only intermittently reinforced, the overall R\*S varied down to zero. The responding was maintained even though a shock sometimes closely followed the avoidance response. The responding even continued when the R\*S interval was the same as the mean S\*S. The low response rates of Dinsmoor's animals probably assured adequate contact of the animals with the various S\*S intervals. In neither of the above experiments was the

behavior conditioned with the variable S\*S procedure; conditioning data with a variable S\*S does not seem to be available.

In both of the variable S\*S studies, but especially in the Dinsmoor one, it is hard to see how the subtle changes in shock rate produced by the avoidance response could be directly detected by the rat and related to the avoidance response. In the CAR analysis the animal in a sense uses the relative aversiveness of different responses to average the frequency and closeness of shocks to various responses over an appreciable period of time. The CATS analysis uses the relative aversiveness of different PRTs and PSTs to average the temporal relation of shocks to the avoidance response over a period of time. Obviously these averages would reveal small differences in the average relation between responses and shocks that could not be detected in the individual cases with a variable S\*S and R\*S. In addition the averages single out the avoidance response as different from other responses.

In summary, the attempt in Possibility 3b to develop a satisfactory alternative to CATS, CAR, and Omission does not seem successful. The possibility of more direct reinforcement by relating the change in shock rate or IST distribution to the response remains vague and has serious unsolved difficulties.

Sidman has recently (1962a) suggested that "reduction in shock density be considered an important variable in avoidance behavior". However his formulation is not yet available in enough detail to determine whether he is developing Possibility 3a, 3b, or the omission one. His proposal is accompanied by results that are quite relevant to the present analysis, and they will be discussed after other problems are dealt with.

## APPLICATION OF CATS FORMULATION TO RELEVANT DATA

There is now extensive literature on the Sidman avoidance procedure and numerous modifications. Some of these results may at first seem hard to reconcile with a temporal discrimination analysis, so let us examine how the CATS formulation handles these results.

### 1. *Variable Intershock Time*

An essential feature of the CATS conception is the proposal of separate discrimina-

tions of both the R\*S and S\*S intervals. In the discussion of the omission and shock rate viewpoints, the difficulties that confront the attempt to make an IST discrimination describe all Sidman avoidance behavior have been seen. Once the animal begins to respond, the IST usually becomes highly variable, so usually the time of the next shock cannot be predicted from the last shock (Sidman, 1953a, p. 158). However, when it is recognized that the rat develops a discrimination of both the R\*S and S\*S intervals, then the difficulty with a variable IST disappears. The discrimination of the R\*S interval is well known and often illustrated; the discrimination of the S\*S is less frequently discussed, but Fig. 10 (after Sidman, 1952, and to be discussed later) shows it. Another published figure has been given by Sidman (1958, Fig. 1). When the R\*S and S\*S are different, then the distinctness of the two discriminations is more apparent; Fig. 3 presents data obtained in our laboratory with a 15-sec R\*S and a 10-sec S\*S interval. The curves in both intervals begin at about the same low probabilities, and rise to about the same high probabilities. But the R\*S curve rises later than the S\*S one, a difference appropriate to the greater length of the R\*S interval.

Thus, when there has been no shock since the last response, then the R\*S timer is controlling and it is the temporal stimuli timed from the last response that are important to the rat. It is these PRT stimuli that are made

aversive by a fixed and highly reproducible relation to shocks. Here the variability of the IST is of no consequence. On the other hand, when there has been no response since the last shock, then the S\*S timer is controlling and it is the temporal stimuli timed from the last shock that are the relevant stimuli for the rat. It is these PST stimuli that are made aversive by a fixed temporal relation to the shocks. Thus, when the R\*S and S\*S situations are considered separately, then the shock does occur at highly reproducible times to which the rat can and does react. However, the rat times from the response in the one situation, and from the shock in the other, just as the controlling equipment is doing.

## 2. Variable R\*S

There have been investigations of several avoidance procedures that produce a variable R\*S interval. These procedures have maintained avoidance behavior, and one procedure has conditioned avoidance behavior without previous training. These results have raised the question of how the animal could time the R\*S interval when the interval keeps changing (Sidman, 1953a). Although the sharp discriminations that result from a constant R\*S do support the CATS formulation, still it turns out that a constant R\*S is not at all essential for the CATS formulation. All that seems necessary for reinforcement is that the aversiveness of the temporal stimuli be less after a response than at longer PRTs.

A variable R\*S results from the intermittent delivery of shocks programmed on the Sidman schedule (Boren and Sidman, 1957), but with this procedure the actual R\*S intervals received by the animal are not predictable from the procedure alone, since they depend on how the animal responds. Analysis is much clearer with shock-contingent variation in the R\*S interval as described by Sidman and Boren (1957); there one can specify the frequency of shocks at the various times after the avoidance response. The basic explanation is the same in both experiments, so let us analyze a representative case of shock-contingent variation, namely, the case where each of the five different R\*S intervals, 4, 10, 15, 20, and 25 sec, occurred before one-fifth of the shocks. In the usual Sidman procedure, the rat is shocked whenever PRT equals R\*S. In the variable R\*S procedure the rat usually received a shock

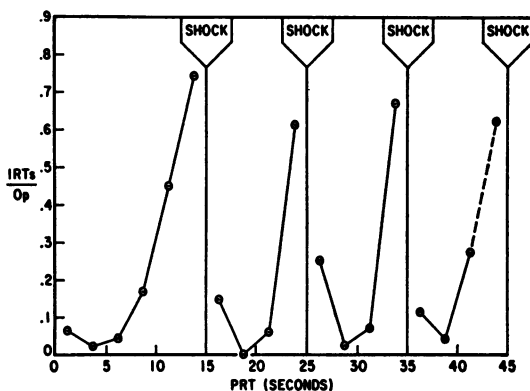


Fig. 3. Different discriminations during a 15-sec R\*S interval and 10-sec S\*S intervals as shown by the IRTs/Op estimate of the probability of response. The data were obtained during five 2.5-hr experimental periods on successive days. The opportunities for response were over 20 for all points except the point for 42.5 to 45-sec IRTs where there were 16 opportunities.

when the PRT equaled the longest R\*S interval, 25 sec in the present case. (Not always, because sometimes the rat received a shock at a shorter R\*S, *e.g.* 15 sec, and then due to continued non-response, received the next shock at a 35-sec PRT, since S\*S equaled 20 sec.) On the other hand, the rat reached 4- and 10-sec PRTs many times without receiving a shock there. Hence the probability of a shock at short PRTs, *i.e.* the shocks per exposure to short PRTs, was much lower than at long PRTs, even though both 4-sec PRTs and 25-sec PRTs received one-fifth of the shocks. As mentioned earlier, shocks per exposure seems a likely candidate for major importance in determining the relative aversiveness of different PRTs.

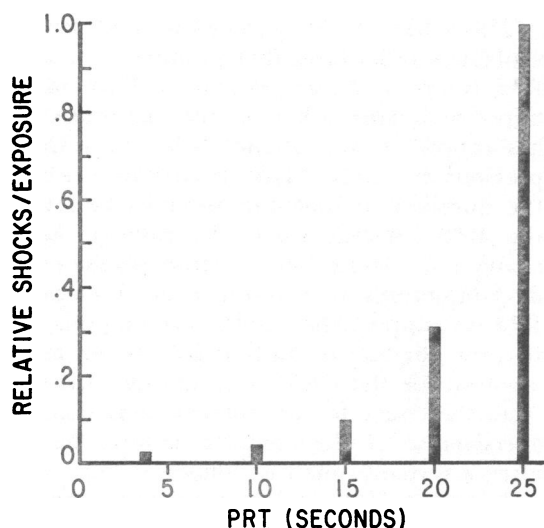


Fig. 4. The shocks per exposure at different PRTs relative to the shocks per exposure at 25-sec PRTs calculated from data published in the Sidman and Boren (1957) report on shock-contingent variation in the R\*S interval.

To demonstrate this difference in shocks per exposure, the relative number of exposures to different PRTs was calculated from the

\*There are two minor errors in Fig. 4 in addition to the error of estimation from the published figure. (1) Exposures to 15-sec and 25-sec PRTs had to be estimated by interpolation from the exposures at 14 and 16, 24 and 26 sec. (2) An S\*S interval after a 4-sec PRT will produce a shock at a 24-sec PRT. Since the frequency of S\*S intervals after 4-sec shocks was not available, the shocks per exposure at 24-sec PRTs could not be plotted on the graph. But for the analysis presented, it makes no difference whether their level is high or low.

data in Fig. 2 of Sidman and Boren. Since roughly the same number of shocks was given at the five different PRTs, the relative shocks per exposure at the five different PRTs can be estimated. The results of this estimation are presented in Fig. 4 for rat GF-66.<sup>4</sup> The absolute shocks per exposure is not easily determined from the available data, but the relative shocks per exposure is sufficient to show the great difference in shocks per exposure between long and short PRTs. The shocks per exposure at the shortest PRTs were so low that they would be expected to have little effect on the relative aversiveness curve. From the CATS point of view the change from a fixed 20-sec R\*S to the variable R\*S analyzed above would be expected to produce little change in behavior, probably a small increase in medium and short IRTs. This is what Sidman and Boren reported.

From the CATS point of view the shocks per exposure curve could be quite different from that shown in Fig. 4 and maintenance of behavior would still be expected if approached properly. The major requirement seems to be that for a sufficiently long range of PRTs the conditioned aversiveness would have to be substantially greater than it is soon after a response. If the conditioned aversiveness rises to moderate or high values only at long PRTs, then the treatment should be roughly similar to a long R\*S Sidman schedule; if the rise occurs at short PRTs, then the treatment should be similar to a short R\*S Sidman schedule.

The above presentation is over-simplified since only the average situation is considered. Wide variation in the R\*S would be expected to produce considerable inhomogeneity in behavior. At one moment, 4-sec and 10-sec PRTs would be made somewhat aversive; at another time no shock would be given until a 25-sec PRT occurred (and in some schedules tested by Sidman and Boren, an 80-sec PRT). Consequently, one would expect a somewhat higher response rate for a while, then a long extinction when shock delivery waited for the occurrence of a PRT equal to the longest R\*S. Sidman and Boren commented on such behavior and illustrated it in their Fig. 3. As explained below, this inhomogeneity would produce the observed flattening and shifting of the response-probability peak to longer PRTs as the R\*S range was increased.

Sidman has recently described an adjusting schedule (1962b) where the rate of responding affects the R\*S interval (response-contingent variation in the R\*S). In this adjusting procedure a bar press delayed shock for 5 sec as in the usual Sidman avoidance, but each additional response before the shock added 5 sec more to the time which had to elapse before the next shock occurred. Thus, rapid responding could produce long R\*S intervals up to a maximum of 50 sec. Animals were trained from the start with this procedure.

This procedure provided a variable R\*S with a minimum of 5 sec and a range from 5 sec to 50 sec. Figure 2 of Sidman (1962b) shows that a large proportion of the shocks occurred at R\*S intervals between 5 and 15 sec. Therefore, the analysis presented earlier would predict as a first approximation that the behavior on this schedule would be similar to that on a 5- or 10-sec R\*S Sidman schedule. This is supported by the fact that the response rates seem comparable to those from a 5-sec fixed R\*S. The response rate for animal CB-17 was about 13 responses per min (measured from Fig. 5). Since the response probability shown in Fig. 1 averaged around .7 for most animals, the rate of CB-17 seems reasonably typical of the other animals. In Sidman's (1953b) comparison of different fixed R\*S intervals, he found a 4-sec R\*S gave a mean response rate of 12.1 responses per min, and a 7-sec R\*S gave a mean of 14.6 responses per min. (Numerical data available from Sidman, 1952, or from ADI, see footnote 3 of Sidman, 1953b.) Thus, it is reasonable to propose that the animals in the 1962b experiment were on a variable R\*S with so many shocks at a 5-sec R\*S that the effect of the procedure was close to that of a 5-sec fixed R\*S.

Sidman (1962b) reported that only one animal, CB-17, showed evidence of a temporal discrimination when IRTs were grouped in 5-sec wide groups. The analysis above leads to the expectation that most of the increase in aversiveness would occur below 5 sec, so a discrimination would not necessarily be visible with 5-sec grouping. As in earlier analyses, the curve of shocks per exposure against PRT will probably prove more useful in understanding this procedure than the number of shocks against PRT as plotted in Fig. 2 of Sidman 1962b. A replot of Fig. 2 in terms of shocks per exposure would probably still show

a peak at 5 sec for rats such as CC-11 (though a lower peak), but for rat CB-17 the 5-sec peak might be replaced by a curve of increasing shocks per exposure out to longer PRTs. This agrees with the observation that this animal was the one that displayed a fair temporal discrimination when 5-sec compartments were examined.

This schedule has another important property which complicates its effect. The adjusting schedule selectively reinforces short IRTs and groups of them (bursts). A group of short IRTs will only be followed by shock after long time intervals ranging up to 50 sec, while an isolated response is followed by a shock in 5 sec. There is evidence (Anger, 1956, pp. 160-161) that rats can discriminate to some extent between a group of short IRTs before the last response and no short IRTs before the last response. Consequently it would be expected that the temporal stimuli following a group of short IRTs would have a lower aversiveness than the temporal stimuli following an isolated response. Thus, the animal would be reinforced more, would lower the aversiveness more by a group of short IRTs than by an isolated response. This selective reinforcement of groups of responses at a high rate should make this procedure considerably more effective than an ordinary 5-sec R\*S Sidman schedule in developing the high response rate necessary for avoidance with a 5-sec R\*S. This factor may explain the successful conditioning with the adjusting schedule whereas difficulty is encountered in conditioning from the start with a 5-sec fixed R\*S.

The above-described property complicates considerably the detection of the temporal discrimination produced by the adjusting schedule. The selective reinforcement of responses at short PRT stimuli will raise the low response-probability there that ordinarily is kept low by the PRT discrimination. A response at 3- to 5-sec PRTs is reinforced by a decrease in aversiveness, but then a following group of responses at short PRTs is also reinforced by a further decrease in aversiveness. Stimuli both from the PRT and from the preceding IRTs probably control the aversiveness. Consequently a simple plot of response probability versus PRT may show no discrimination even though PRT discrimination is occurring. This can result because the discrimination, the way

the responding varies with PRT, depends on the preceding IRTs. If that dependence is ignored, and the response distribution following several short IRTs is combined with that following a long IRT, then the mixture may not reveal either discrimination. (See discussion of inhomogeneity below.) It may be necessary to take into account a moderate number of preceding IRTs to see the discrimination.

### 3. Variable R\*S Including Punishment

In the variable R\*S procedures just described there was a lower limit on the R\*S (though perhaps there need not have been in all cases). Results have been published on two techniques with no lower limit on the R\*S. Avoidance was obtained even though the avoidance response sometimes was closely followed by shock, *i.e.*, was punished by shock. One procedure was described by Sidman (1962a) in connection with the already-mentioned proposal that reduction in shock density be considered an important variable in avoidance behavior. This procedure delivered a shock to the animal whenever either of two independent recycling timers (A and B) reached the end of its timing cycle. Timer A reset and began timing again whenever it delivered a shock and also whenever the animal pressed bar A, one of two available bars. Timer B reset and began timing again whenever it delivered a shock or whenever the other bar, B, was pressed. If the rat continued to press only one bar, it would continue to get the shocks programmed by the timer connected to the other bar. Sidman found that most animals developed appreciable response rates, though high rates on one bar and relatively low rates on the other were often seen. Consequently, shocks followed some of the responses that occurred on the bar with the high response rate. These punishment shocks were delivered by the timer connected to the other bar that had the low response rate.

The CATS formulation does provide reinforcement of bar pressing in this situation in spite of the punishment. Consider the situation with respect to pressing bar A. Timer A delivers shocks only at fixed times following bar-A presses, say 20 sec. Therefore the shocks per exposure will be 100% at 20-sec PRTs. Timer B is independent of bar-A presses, so the shocks that it produces will tend to occur with about equal frequency at all different

times after bar-A presses. Hence, timer B will produce equal but relatively low shocks per exposure at different times following bar-A presses. When all the shocks are considered together, equal but relatively low shocks per exposure occur at all times after bar-A presses, except at certain long times after bar-A presses where there are 100% shocks per exposure. Consequently, a rise in aversiveness with time after bar-A presses would be expected. This would provide a decrease in aversiveness following bar-A presses even though the aversiveness following a response would not be as low as in ordinary Sidman avoidance. The same would be true for bar-B presses of course, but Sidman's data indicate that rats in this situation develop strong bar preferences. Sidman's Fig. 9 showed the development of good temporal discriminations in this situation. Various other processes such as superstitious reinforcement of switching between the two bars could complicate the interpretation of this procedure, but these cannot be analyzed adequately without additional data.

From the CATS point of view, each avoidance response except those at short PRTs or PSTs would be reinforced somewhat by a decrease in aversiveness following the avoidance response. In Sidman's proposal that the response is reinforced by the reduction of shock density, it is unclear what measure of shock density is reduced (shocks during what time intervals), and how that reduction is related to the avoidance response once the behavior stabilizes. There do not seem to be many cases of reduction in shock density following responses; as pointed out, responses are sometimes followed by shock. The average shock density appears to be rather constant throughout long stretches of the published records. Even with the radical proposal that the animal is comparing the current shock density with some sort of "record" of the shock density received some time ago when there was no responding, the problem still remains of how the differences in shock density are brought to focus on the particular response selected by the experimenter as the avoidance response. Other responses are still occurring along with the avoidance response.

The CATS analysis predicts that, other things being equal, there will be a tendency for the high rates of response to occur on the bar with the shorter R\*S. This is predicted



because responses on that bar will be punished less than responses on the other bar since the timer wired to the other bar has the longer R\*S. Although the observed considerable preference for one lever causes other things to be unequal, and obscures this effect, Sidman pointed out that there was some tendency for this effect to occur.

The other procedure with R\*S variation to the degree that includes punishment is the control procedure (no signal) reported by Dinsmoor (1962). His experiment was mentioned in connection with Possibility 3b, and its analysis in terms of CATS is sufficiently close to the above that it need not be treated in detail. Dinsmoor pointed out that with this procedure, even though shocks sometimes occur right after a response, they are somewhat less likely soon after a response than at longer times after a response. Thus, a rising CATS aversiveness curve is generated, and the avoidance response would be followed by a decrease in aversiveness.

#### 4. Variable S\*S

The available data on a variable S\*S and the difficulties it poses for the omission and the shock-frequency-decrease formulations have already been discussed. It has been pointed out that a variable S\*S will eliminate PST reinforcement, but it would have little effect on PRT, and PST plus PRT reinforcement by CATS. Consequently, a variable S\*S would not be expected to prevent conditioning. With separate temporal discriminations of the R\*S and S\*S intervals the CATS formulation solves the problems that plague the omission and shock-frequency-decrease formulations, *i.e.*, the maintenance of well-developed Sidman avoidance and conditioning with a variable S\*S.

#### 5. Response Chains and Other Collateral Behavior

Collateral behavior, usually called response chains, has occasionally been observed during temporal discriminations (Wilson and Keller, 1953; Bruner and Revusky, 1961), with delayed reinforcement (Ferster, 1953), and with delayed matching (Blough, 1959). Bruner and Revusky (1961) proposed that with humans the response chains played a functional role, *i.e.*, the temporal discriminations depended on the response chains. However, there has

not yet been any demonstration that this collateral behavior is essential for the discrimination; so far, only its presence seems to have been shown during some cases of temporal discrimination. It should be possible to determine whether the collateral behavior affects the discrimination by manipulation of either, and observation of whether the other is changed with maintenance of some relation between the two. Blough (1959) did show that the matching responses in two of his four birds were dependent on the behavior during the delay. However, the collateral behavior in Blough's situation did not seem to have any timing role. Furthermore, the behavior of his two birds with mediating chains was quite unstable and easily lost in contrast to the stability of the other two birds where mediating chains played no apparent role. In the case of temporal discriminations, drugs might help show the relation between collateral behavior and timing. Amphetamine and other drugs are known to change the temporal discrimination obtained with food reinforcement of only long IRTs (Sidman, 1956; Schuster and Zimmerman, 1961). Will some relation between the response chain and the IRT distribution remain unchanged under the influence of the drug; or will the chain and the IRT distribution vary independently?

It seems desirable to distinguish at least three different types of collateral behavior that may influence temporal discriminations; (1) the heterogeneous chain, a recurring chain of different responses; (2) the homogeneous chain, the repetition of a series of quite similar responses; and (3) competing behavior. These collateral behaviors are developed by the animal without assistance from the experimenter in the form of changes in stimulation between members of the chain, *etc.* Chains of response built up deliberately by the experimenter with environmental stimulus changes and different contingencies are obviously quite a different matter.

(1) The term heterogeneous chain has been applied to a repeated sequence of different responses (*e.g.* Herbert and Arnold, 1947; Keller and Schoenfeld, 1950). Wilson and Keller (1953) reported observing such chains of response with food reinforcement of only long IRTs. The behavior of one subject of Bruner and Revusky (1961) on a similar procedure may fall in this class. Apparently a

stable heterogeneous chain could provide the timing for a sharp temporal discrimination with food reinforcement. However, temporal discriminations based on food reinforcement have been repeatedly described without observable chains of other responses between the initial event and the reinforced response (Anger, 1956; Kelleher, *et al.*, 1959; Reynolds and Catania, 1962). Therefore, it is doubtful that visible heterogeneous response chains are necessary for temporal discrimination.

Although heterogeneous chains have been reported with food reinforcement, there does not seem to be any published report of chains playing an appreciable timing role in Sidman avoidance. In an experiment with concurrent Sidman avoidance and variable-interval food reinforcement, Sidman (1958b) found that monkeys develop a high frequency of food-lever responses followed by avoidance-lever responses. This sequence was maintained after discontinuing the food reinforcement. Apparently after food reinforcement had raised the food-lever frequency high enough, the avoidance reinforcement maintained the sequence of two responses in the superstitious manner (Skinner, 1948). However, the two responses could be made very close together, in fact simultaneously by using both hands, so there is no evidence that this chain of only two responses was of any significance for timing.

N. Azrin (personal communication) had one rhesus monkey develop a stereotyped response between reinforced bar presses. The procedure, although basically Sidman avoidance, was somewhat unusual: the aversive stimulus was a loud noise; S\*S was zero and escape responses were reinforced, *i.e.*, the noise stayed on continuously until terminated by a response. The procedure failed to generate the low frequency of aversive stimuli commonly seen when shock and monkeys are used. The stereotyped response consisted of circling the 4-ft-long cage and pressing the bar once or twice during almost every circuit. The R\*S was increased until it was much longer than the IRT generated by the circling, but there was no appreciable change in the circling.

In the formation of chains, Sidman avoidance seems to present a quite different situation from that of food reinforcement of long IRTs. The formation of chains of response with food reinforcement is attributed in part

to the superstitious reinforcement of behavior that precedes the response essential for reinforcement. The extension of the chain for any length probably requires further superstitious reinforcement of additional responses by the conditioned reinforcing action of stimulation associated with responses already learned (Wilson and Keller, 1953). But in Sidman avoidance, the conditioned stimuli that precede the reinforced response are aversive, and it is their termination that reinforces, not their onset as with food reinforcement. Dinsmoor (1954, pp. 43-44 especially summary on p. 44) has pointed out that when members of a chain are made aversive, this tends to disrupt the chain. In fact he and others propose that this is the main way a punishment depresses the preceding behavior. An aversive response in a chain disrupts the chain because it makes the chain into an avoidance situation where chain-disruption is reinforced. The responses of the chain that regularly precede the aversive response will act as warning stimuli preceding an aversive event. Consequently, the animal will learn different responses that break the chain because such breaking terminates aversive stimuli. Thus, the view that a response chain provides the timing in Sidman avoidance seems incompatible with both the CAR and CATS formulations. In fact, accurate timing by response chains seems incompatible with any view that treats the avoidance response as escape from conditioned aversive stimulation, because any such view has a response chain leading up to an aversive event. This incompatibility, plus the almost complete absence of empirical evidence for chains in Sidman avoidance, were the basis of the proposal that the conditioned aversive temporal stimuli do not result from response chains, but instead have other sources.

The difficulty with the response-chain theory seems to result from the indirect relation between the conditioned aversive stimulus and the time since the last response. The indirect relation gives the rat too much control over the conditioned aversive stimulus. A wide variety of responses besides avoidance will break the chain and thereby eliminate the aversive stimuli arising from the chain; the avoidance response need not be made. Thus, the response chain provides a faulty model of the Sidman avoidance contingencies. With a

stimulus which depends only on the time since the last avoidance response, the only response that will change the aversiveness of this stimulus is the avoidance response. This model more accurately mirrors the Sidman contingencies, since the only way to prevent the shock is to make the avoidance response. Consequently, this model provides a superior basis for Sidman avoidance responding. (Of course the situation is complicated by the PST stimulus as well as the PRT, but the same conclusion holds.)

Would the reinforcement from CATS tend to produce response chains when the temporal stimuli have some other source besides the response chain? Probably not, because the response chain would still generate warning stimuli preceding the aversive stimuli. The avoidance situation that produces chain-breaking responses would remain.

Sidman's (1958b) report of superstitious reinforcement of an extraneous response along with the avoidance response does not seriously detract from the above analysis because the response sequence involved was so short. It seems reasonable that the decrease in aversiveness of CATS following the avoidance response could superstitiously reinforce one or two responses simultaneously with, or just preceding, the avoidance response. These responses close before the aversiveness decrease probably could be reinforced enough by that decrease to make up for their pairing with the aversive CATS. (The avoidance response itself is paired with aversive CATS but the following aversiveness decrease compensates.) This is quite different from a complex stable chain of responses that starts long before the decrease in aversiveness, and is able to time accurately a 20-sec interval (Fig. 11).

The behavior Azrin observed may have a similar explanation, since the extraneous response, walking, occurred while the monkey pressed the bar. This may have reinforced walking about the cage, a behavior with high strength in some monkeys without deliberate reinforcement.

(2) Homogeneous chains were seen by Bruner and Revusky (1961) in three of their four human subjects reinforced with money. These three subjects seemed to make roughly the same response repeatedly before making the reinforced response. To hold this behavior responsible for a sharp temporal discrimina-

tion at moderate time intervals, one has to make the additional assumption that the organism is discriminating the number of intervening responses. Rats have been trained to make a given response after some number of other responses (Mechner, 1958), but it was not determined whether these results involved a number discrimination or a temporal discrimination along with a stable rate of response. If in Sidman avoidance the rat is discriminating some number of responses, then that number and numbers close to it would be expected to become aversive stimuli and disrupt the chain just as aversive components do in the heterogeneous chain. So with homogeneous chains the same basic factors opposing chain development would exist as were described with heterogeneous chains, only complicated by the additional number discrimination.

(3) The third collateral behavior that might play some role in temporal discriminations is competing behavior, behavior between avoidance responses that might be quite variable and unorganized, though it need not be. Such behavior would not be a means of timing; it would not, by itself, produce the sharp discriminations that are found. But competing behavior may influence a temporal discrimination considerably by lowering the probability of response until a temporal stimulus from some other source raises the probability. With food reinforcement of only long IRTs, this delaying action of competing behavior might lead to its differential reinforcement. The elimination of this behavior would affect the discrimination even though the competing behavior was not responsible for the accurate timing.

Observations of animals on Sidman avoidance in this laboratory have not produced any evidence for either consistent heterogeneous or homogeneous chains between the avoidance responses. Some animals sit without activity between bar presses; others engage in various activities part of the time, but without any appreciable consistency in the sequence of responses for a given animal as required by the chain theories. However, evidence which will be published elsewhere is beginning to indicate that disorganized competing behavior may have an important influence under some conditions, but without being responsible for the accurate timing.

### 6. Temporal Discriminations

Reinforcement by CATS requires differences in aversiveness at different PRTs and PSTs. When such differences are present, differences in the response probability at different PRTs and PSTs, *i.e.* temporal discriminations, ordinarily would be expected. However, in connection with the adjusting schedule, it has been shown that there can be additional processes which reinforce short IRTs. In that case, unless sequential data is taken into account, those processes will reduce the differences in response probability by which differences in aversiveness are currently detected. There appear to be other processes that generate short IRTs in ordinary Sidman avoidance. The frequent (but not invariable) occurrence of a high probability of short IRTs has often been noted and has been analyzed by Sidman (1958a). There are many explanations for these responses and they probably do not all have the same origin. Some are probably produced in ways far removed from the decrease in aversiveness of CATS, such as a bar that bounces. There is at least one way that CATS may contribute to these short IRTs. Consider two avoidance responses in succession,  $R_1$  and  $R_2$ , where  $R_1$  occurs at a long PRT, and  $R_2$  at a very short PRT.  $R_1$ , as well as the sequence  $R_1R_2$ , may be reinforced somewhat by the large decrease in aversiveness encountered at the long PRT. This is especially so if the circuit employed is such that a response does not, within a few msec, eliminate the possibility of shock. If it does not, single responses will sometimes be closely followed by shock, but pairs will not, thus the aversiveness will be less following a short IRT than following a single response. There is neither the space nor the data to deal adequately with the problem of short IRTs here. Clarification of the source of these responses and elimination of them seems quite desirable for the study of Sidman avoidance. For the present, however, let us examine the temporal discrimination data in spite of this problem. How consistently do temporal discriminations develop with Sidman avoidance, and how early in training do they develop? Before the data relevant to these questions can be evaluated it is necessary to consider how temporal discriminations should be measured and the problem of inhomogeneity.

### *Measurement of temporal discriminations.*

What statistic should be used to detect temporal discriminations? The relative frequency of different IRTs has been used, and so has the cumulative frequency curve. Sidman (1954) concluded from their examination that Sidman avoidance conditioning was not a product of a time discrimination. He showed that precise temporal discriminations sometimes do develop, but concluded that in either their mild or extreme form, they appeared only after prolonged training, and were not necessary for original conditioning.

It has been pointed out (Anger 1956) that there are reasons for believing that comparison of the relative frequency of IRTs may be inappropriate for many purposes. The animal has many more opportunities for a response at short times after the last response than at long times. Every response is followed by an opportunity for making IRTs between 0- and 4-sec long, but with a high response rate the animal may rarely go 20 sec without a response and consequently there may be few opportunities for IRTs 20- to 24-sec long. (The number of opportunities for a given band of IRTs equals the number of IRTs in the sample that are longer than the lower limit of the band.)<sup>5</sup> The presentation of short PRT stimuli more often than long PRT ones should result in more short IRTs even when the probability of response to the two stimuli

<sup>5</sup>An exposure to a PRT is nearly the same as an opportunity for response to a PRT, and for most purposes the differences can be ignored. However, two different terms are used, not only because opportunity seems more appropriate to a response and exposure to stimulus, but also because, if we are rigorous, there are slight differences. Exposures will be defined as follows: For each IRT, an animal will be said to have had an exposure to all PRTs from zero to the PRT at the time of response. These definitions generate slight differences between the two terms: 1) Strictly speaking, the probability of the occurrence of exactly a certain value of a continuous variable is zero. Consequently, with probabilities of response, and hence opportunities, one must refer to a band of PRTs of finite width. However, it is meaningful to speak of an exposure to an exact PRT; a 20-sec IRT involves exposure to a 10-sec PRT, and many other PRTs. 2) A response at a 13-sec PRT results in exposure to all PRTs in the 10 to 12-sec PRT band. A response at an 11-sec PRT is *different* because it results in exposure to only half of the PRTs in that 10 to 12-sec PRT band. On the other hand, the 13-sec PRT and the 11-sec PRT each are just the *same* as far as opportunities go. Both contribute 1.0 opportunities for response in the 10 to 12-sec PRT band.

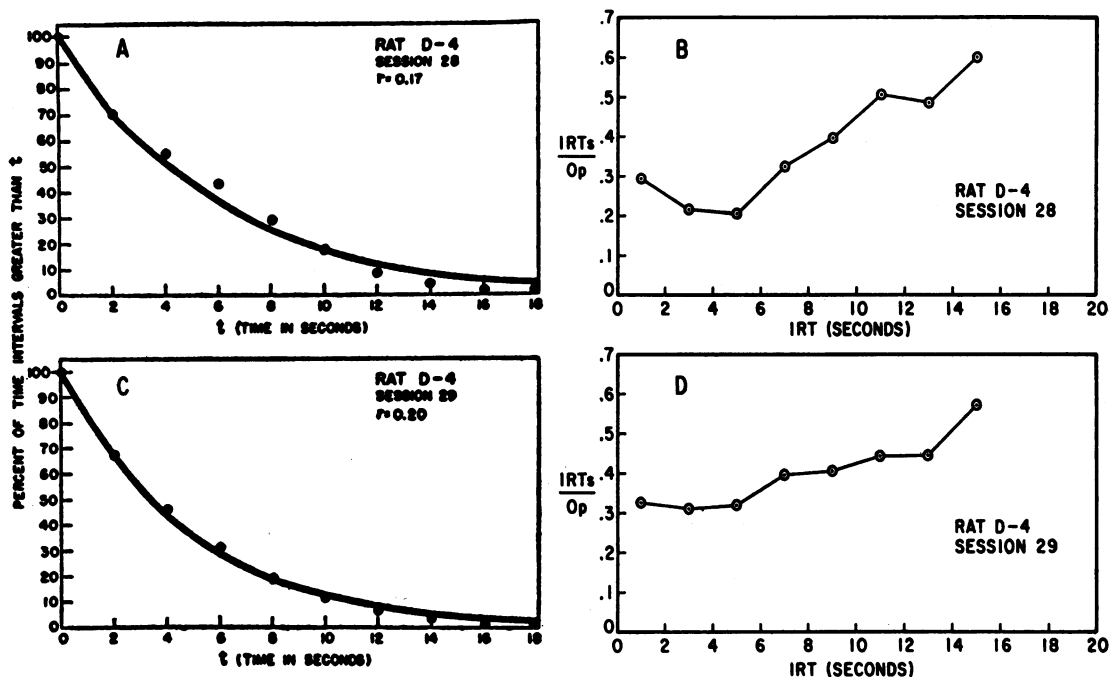


Fig. 5. A and C are copies of Fig. 2 of Sidman (1954) whose caption was: "The percentage of interresponse time intervals greater than  $t$ , where  $t$  is time in seconds. Rate of responding in responses per second is  $r$ . The line through the data is a plot of the equation  $P_{>t} = e^{-rt}$ ." B and D give the same data as A and C respectively, but recalculated to show IRTs/Op. R\*S and S\*S were both 20 sec.

is the same. This artifact is easily eliminated by calculating the IRTs in a band per opportunity for response in that band,  $IRTs/Op$ . (For more information on this statistic see Anger, 1956.)  $IRTs/Op$  is a statistic that estimates the probability of response in a certain time interval on the condition that the animal reaches the initial boundary of the interval, and hence has an opportunity for response in the interval. This population variable will be called the *conditional probability of response* hereafter.

The discrimination point of view and the desirability of the  $IRTs/Op$  statistic is further supported by data from reinforcement with food (Anger, 1956; Kelleher, *et al.*, 1959). During the initial training, before there is time for much discrimination to develop, one would expect approximately equal response at different PRTs. Rough equality is found in the  $IRTs/Op$  statistic. Nothing near equality is found in the relative frequency distribution, due to the much greater number of opportunities at shorter PRTs. Consequently, it seems that failure to find evidence for a temporal discrimination in the relative frequency

distribution of IRTs is not convincing; the  $IRTs/Op$  curve should also be studied.

Sidman in 1954 presented most of his data as graphs which showed how the percentage of IRTs longer than some duration,  $t$ , varied with the value of  $t$ . (This distribution will be called the *cumulative frequency distribution*, although the cumulation is from right to left instead of the usual left to right.) To evaluate whether a temporal discrimination was present he compared the distribution produced by the animal with one for "random responding," *i.e.*, with one for a constant conditional probability of response, given by the exponential distribution. This comparison is based on the assumption that when the conditional probability is constant, there is no temporal discrimination. Thus Sidman, in his comparison of theoretical and empirical cumulative frequency distributions, evaluated in an indirect way whether the conditional probability of response was constant or whether it changed in a certain way, just as Anger did somewhat more directly with the  $IRTs/Op$  statistic. These two approaches seem to agree that a temporal discrimination constitutes a devia-

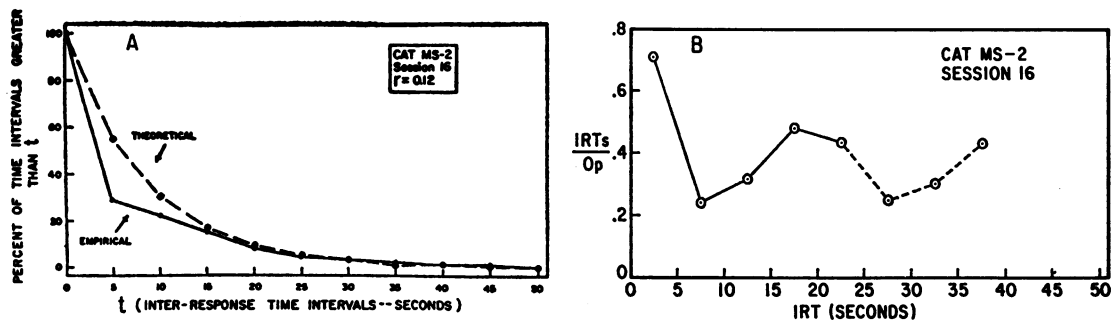


Fig. 6. A is a copy of Fig. 3 of Sidman (1954) whose caption was: "An example of the Type I deviation from the theoretical assumption of random responding. R-S interval = 45 sec., and  $r$  is response rate in responses per second." B gives the same data recalculated to show IRTs/Op.

tion from constant conditional probability. There also seems to be no difference in the *validity* of the evaluation of the constancy of the conditional probability whether it is done by determination of the equality of the IRTs/Op for different IRTs or by comparison of the actual cumulative frequency distribution with the exponential distribution. However, there may be a great difference in *sensitivity* of the two techniques to temporal discriminations.

Sidman's data (1954) showed that the empirical and theoretical cumulative frequency distributions often were remarkably close together. His figures are reproduced here as Fig. 5A, 5C, 6A, 7A, and 7C (the left-hand portions of the three figures). The IRTs/Op curves were calculated from the published data for each of the figures of Sidman (1954) where that was possible.<sup>6</sup> In Fig. 5B, 5D, 6B, 7B, and 7D the IRTs/Op curves are presented to the right of Sidman's original figures.

It is apparent that in four of the five cases the IRTs/Op curve rises at long IRTs and thereby indicates a temporal discrimination. The discrimination has not become precise at the time of Fig. 5, but with a rising IRTs/Op curve, and no evidence that the rise is

not significant, it cannot be concluded that discrimination is absent. In both halves of Fig. 7, which are used to illustrate Type I and II deviations (Type II deviation being the temporal discrimination), the IRTs/Op curves show evidence of temporal discriminations despite the different relations between theoretical and empirical cumulative frequency distributions. In Fig. 6, which presents data from a cat, the case for a discrimination is not clear. However, the errors in deriving the IRTs/Op curve (to be discussed below) were much greater in this case than in the others, and the R\*S interval was much longer.

How can the observed cumulative frequency curve be so close to the constant probability curve when the IRTs/Op curve is so different from the constant probability one? This complex system cannot be adequately analyzed here, but some comment may be helpful. The IRTs in the last third of the R\*S interval are obviously of considerable importance in evaluating the degree of temporal discrimination. But these IRTs constitute only a small percentage of the total IRTs, because there are so few opportunities for long IRTs. This is especially true before a discrimination becomes well-developed when the moderate IRTs are still quite numerous. The frequent occurrence of a high response probability at the shortest IRTs further reduces the percentage of long IRTs. Consequently, when these percentages are plotted as a cumulative frequency curve, most of the ordinate range is taken up by the much more numerous short and moderate IRTs; and the long IRTs, just short of the R\*S interval, constitute only a very small percentage of the ordinate range. Then, the small variation in the long IRTs,

<sup>6</sup>The IRTs/Op curve could not be calculated for the relative frequency distributions because the number of IRTs at longer intervals was not published. The IRTs/Op curve of Fig. 5 of Sidman (1954) is reproduced as Fig. 11, and is discussed later in another connection; it is not relevant at this time because it illustrated a sharp temporal discrimination. The relative number of responses and opportunities could be calculated from the published data and sufficed for the calculation of the IRTs/Op curves. The absolute number of responses and opportunities in the sample could not be determined; the absolute number is important in evaluating the reliability of the data as discussed in footnote 7.

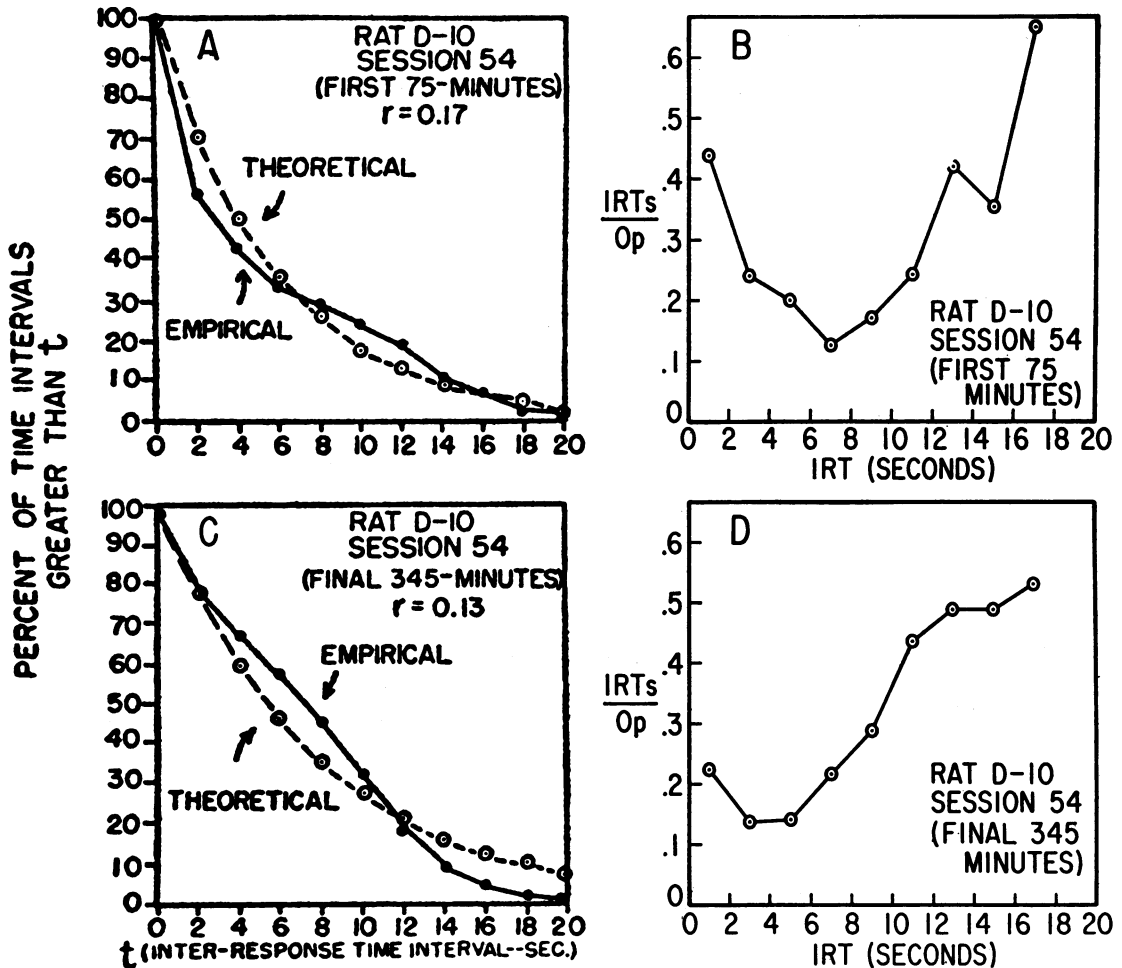


Fig. 7. A and C are copies of Fig. 4 of Sidman (1954) whose caption was: "An example of the shift of the Type I and Type II deviations during a 7-hr session late in training. Response rate in responses per second is noted by  $r$ ." B and D give the same data as A and C respectively, but recalculated to show IRTs/Op. R\*S and S\*S were both 20 sec.

due to the beginning of a discrimination, is hardly visible.

For example, in the two distributions of Fig. 5, less than 9% of the IRTs were longer than 12 sec, even though from 12 sec to the R\*S at 20 sec constituted 40% of R\*S. Consequently, a variation in IRTs/Op from 0 to 1.0 in any of these bands could not change the cumulative frequency distribution even 9% on the ordinate in one of the bands. An appreciable and stable temporal discrimination may involve a change of less than 0.20 in the IRTs/Op. A 0.20 change could not change the curve even 1.8% on the ordinate ( $.2 \times 9\%$ ) in any one of these bands, and would have less effect if distributed among the four

bands from 12 to 20 sec. The width of the line in the cumulative frequency distributions of Fig. 5 is about 2% on the ordinate.

Enlargement of the cumulative frequency curve might make it possible to detect smaller deviations from constant probability, but another problem remains. The interaction between various IRTs makes it difficult to interpret small deviations. Figures 7B and 7D show clear discriminations; both have about 8% of the IRTs between 14 and 18 sec. They differ in that (1) Fig. 7B has a higher IRTs/Op at short IRTs; (2) Fig. 7B has the increase at long PRTs somewhat later than 7D. These are minor differences with respect to whether or not the response probability rises at long

PRTs, but they produce important differences in the relation between the theoretical and observed cumulative frequency curves throughout their entire extent, including the PRTs just short of  $R \cdot S$ .

If a tiny change in the cumulative frequency distribution means a large change in IRTs/Op, then errors in estimation of the IRTs/Op from the published curves will be important. With a reticle magnifier most of the published points could be measured with fair accuracy. Points were omitted when their location was doubtful and the IRTs/Op curve was particularly sensitive (due to low per cent IRTs). To evaluate this measurement error, an attempt was made to eliminate the discriminations by pushing the IRTs in the appropriate direction as far as was at all reasonable. This eliminated the discrimination only in Fig. 6, where it was not clear before. The lower percentage of long IRTs in Fig. 6, as compared with the other figures, resulted in much more uncertainty about the curve beyond 25 sec (the dotted section).

The primary conclusion to be drawn from the above analyses is that examination of the cumulative frequency distribution is not a safe basis for concluding that a temporal discrimination is absent, because that distribution is comparatively insensitive to temporal discriminations, and because it is often most difficult to determine from that distribution how the conditional probability of response changes with time.

The above calculations also indicate that published evidence does not support the view that temporal discriminations are absent early in conditioning. However, the absolute number of opportunities for response<sup>7</sup> at long IRTs in Fig. 5-7 is not known, and the earliest of these curves is for the 16th session. Clearly this question needs more experimental study.

<sup>7</sup>With samples which have 20 opportunities per compartment, if the response probability is about .5, then the IRTs/Op of 95% of the samples will, on the average, fall within a  $\pm .05$  range. Another error results because responses and opportunities are always integers. Under the conditions just specified this rounding-off error seems rarely to exceed  $\pm .04$ . Thus the IRTs/Op is a fairly good estimate as long as there are at least 20 opportunities. With 10 opportunities both errors double. The sampling error is less at probabilities other than .5; the rounding-off error increases somewhat with probability, but at its maximum, and with 20 opportunities, it rarely exceeds  $\pm .05$ .

*Inhomogeneity.* Another major problem for the detection of temporal discriminations results from inhomogeneity. It has been pointed out that inhomogeneity in responding causes the IRTs/Op curve of the aggregate to have a different shape from that of either component alone (Anger, 1956). "Inhomogeneity" refers to the presence of two quite different kinds of responding in one sample, or more precisely, the presence of a large enough difference between the responding in different parts of the sample so that it is highly improbable that the difference results from sampling variation from a single population. The warm-up phenomenon is a well-known example of inhomogeneity. Inhomogeneity tends to be conspicuous early in conditioning, but sometimes it is prominent after long training. It usually is most visible in a cumulative record.

To study the effect of inhomogeneity on the IRTs/Op curve, the IRTs that would be generated by various hypothetical conditional probability curves were calculated. Then, the IRTs from two such curves were totaled and the conditional probability curve of the aggregate was calculated. It turned out that two rising curves may be combined and a quite flat one obtained. When IRTs generated by

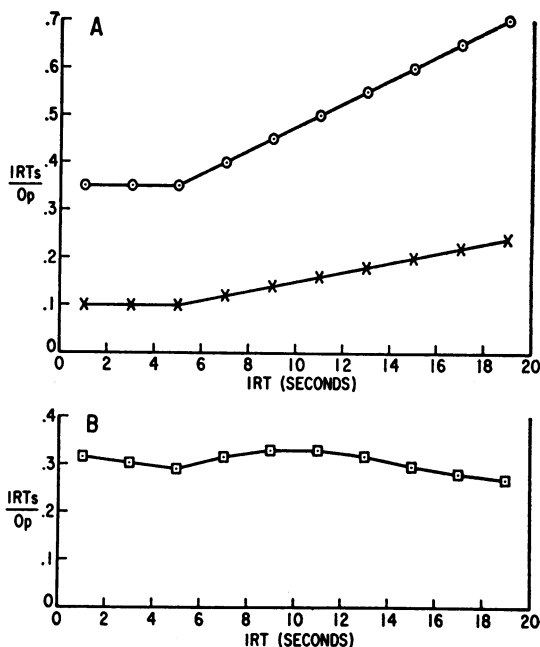


Fig. 8. B shows the conditional probability curve of the aggregate when IRTs generated by the upper curve in A are added to one-sixth as many IRTs generated by the lower curve in A.



the lower curve in Fig. 8A, and six times as many IRTs generated by the upper curve in Fig. 8A are combined, the conditional probability curve of the aggregate is that shown in Fig. 8B. Consequently, if a rat responds most of the time according to the upper Fig. 8A curve, but occasionally according to the lower Fig. 8A curve, there would be no evidence of a temporal discrimination in the IRTs/Op curve of the whole session, Fig. 8B. The temporal discrimination would not be apparent even though, at all times, the behavior was derived from a conditional probability curve that represents a quite clear discrimination (each component curve has at least a two-fold rise). In general, the combination of probability curves with equal positive slopes but different intercepts gives a curve with a lower slope. Consequently, inhomogeneity tends to obliterate the positive slopes that indicate temporal discriminations.

Early in conditioning, before the discrimination has had time to sharpen, the aversiveness at moderate PRTs might be nearly as great as at long PRTs. Hypothetical curves of this general nature are given in Fig. 9A. If responses from the lower curve in Fig. 9A are

combined with twice as many responses from the upper curve, the curve of the aggregate is that shown in Fig. 9B. Inhomogeneity is even more effective at concealing a temporal discrimination when there is an early rise to a high plateau, and inhomogeneity can even change positive slopes into negative slopes.

At long PRTs the combination is determined much more by the low probability component because the high probability component allows relatively few opportunities (and therefore few responses) at long PRTs. At short PRTs with equal samples, the combination is determined about equally by the two components because opportunities will be about equal, but with unequal samples the curve of the larger sample will be weighted more.

The tendency of rats on Sidman avoidance to have a high probability of response at very short PRTs has already been mentioned. Observations in this laboratory confirm the report by Sidman (1958a) that these short IRTs are especially frequent at the start of training. If generalization is high early in conditioning and produces a curve like the upper one in Fig. 9A, but part of the time the rat puts out many short IRTs, then any temporal discrimination will be even more effectively obliterated than it was in Fig. 9.

In view of the difficulties that result from inhomogeneity, the reader may question the desirability of the IRTs/Op calculation. But the inhomogeneity problem does not result from the IRTs/Op calculation; it results from inhomogeneous behavior, the free operant situation, and the comparison of responding at different PRTs. The free operant situation produces different sample sizes at different PRTs, and the dependence of the sample size at any PRT on the response probabilities at shorter PRTs. This dependence, plus inhomogeneous behavior, generates the difficulty in comparing responding at different PRTs. The IRTs/Op measure seems to compare the response probability at different PRTs as directly as possible. Other measures will be affected just as much by inhomogeneity.

*Temporal discriminations after extended training.* It seems to be well-established that extended training sometimes produces clear temporal discriminations in Sidman avoidance. How consistently do they develop with extended training? In the few cases in the

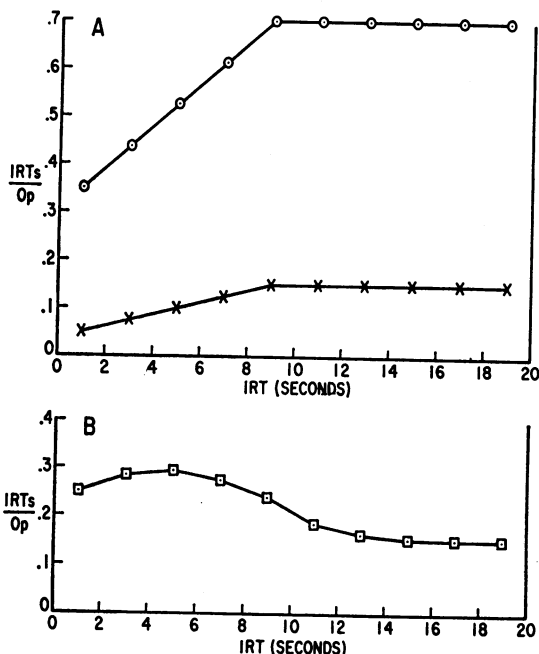


Fig. 9. B shows the conditional probability curve of the aggregate when IRTs generated by the upper curve in A are added to one-half as many IRTs generated by the lower curve in A.

literature where a temporal discrimination is uncertain or doubtful, one is unable to calculate the IRTs/Op curve because the frequency of long IRTs is not given,<sup>8</sup> and the amount of inhomogeneity is unknown. It was demonstrated above that it is unwise to conclude that a temporal discrimination is absent without examination of a IRTs/Op curve which lacks serious inhomogeneity.

In this laboratory, the evidence for a temporal discrimination has sometimes been meager with R\*S intervals longer than 30 sec, even though there was little evidence of inhomogeneity. In these cases it was not clear whether discrimination was absent, or whether there was inhomogeneity of a sort not readily visible in the cumulative curve. A decrease in the importance of CATS reinforcement, and an increase in the importance of CAR reinforcement, may occur at long R\*S values since the sharpness of the temporal discriminations seems to decrease with increasing R\*S.

A special case is that of the occasional rat that develops the pattern of responding once or several times soon after a shock, and then rarely responds again until the next shock. This results in an IST just slightly longer than R\*S and no sign of any temporal discrimination. The frequency of this response pattern is indicated by Weissman's (1962) report on individual differences among 32 rats trained on Sidman avoidance. Cumulative curve C in his Fig. 3 shows clearly that Weissman had one rat with this pattern of predominately postshock responding. Since Weissman used an R\*S of 40 sec, this response pattern would generate slightly less than 1.5 shocks per min. Of his 32 rats, two showed 1.16 and 1.26 shocks per min and one of these was the rat for which the cumulative curve showed this response pattern. Figure 1 of Weissman shows that these two rats gave the highest observed shock rates and represent a group somewhat separate from the rest of the distribution of shock rates (the next four highest shock rates were .79, .70, .59, and .57 shocks per min). Therefore, it is probable that

<sup>8</sup>Experimenters who prefer to publish their IRT data as relative frequency distributions would make their data much more complete and useful to other investigators if along with the distribution they would publish the number of IRTs longer than the longest interval given in the distribution. With this one additional number the IRTs/Op can be calculated by readers.

both these rats showed predominately postshock responding, and there seem to have been few, if any, other rats showing this type of responding. Results in this laboratory confirm Weissman's data: the same pattern has been seen, it is quite uncommon with our equipment, and the stabilized responding seems to be distinct from the usual responding in Sidman avoidance. Thus, under good conditions this response pattern seldom occurs and seems to be a special problem that requires separate study. Additional support for this view comes from the report by Boren (1961) that, in general, responses which closely follow shock differ from other avoidance responses. He found that they are affected differently by drugs than are the usual avoidance response, and that if one bar controls avoidance only, and another bar controls escape only, then the postshock responses are made almost entirely on the escape bar.

With R\*S intervals of 30 sec or less, rare cases have been seen where the IRTs/Op curve shows little evidence of a temporal discrimination even after extended training. In all these cases, however, there were considerable fluctuations between consistent responding at one average rate and consistent responding at other different rates. In all cases encountered here, there were long enough samples of these different types of responding to provide IRTs (measured from a polygraph record) for an adequate IRTs/Op curve of each different type of responding. These individual IRTs/Op curves for the different responding revealed different temporal discriminations. One sample would show an early rise, another a later rise, and the mixture of the two would show no appreciable temporal discrimination for the reasons described in the section on inhomogeneity.

Figure 6B (after Sidman 1954, Fig. 3) showing data on a cat may be a case of this sort. For the reasons mentioned earlier, the curve after 25 sec is quite uncertain due to the error involved in calculating the IRTs/Op curve from the published figure. However, inhomogeneity has produced curves with two peaks like Fig. 6B. In these cases, an analysis of the components shows temporal discriminations in each section. The first peak results from an early rise to a high response probability which generates many responses at medium PRTs. But then at another time dur-

ing the same session the response probability rises later, and produces the response peak at long IRTs. Between the two peaks is a dip where neither response probability curve resulted in many responses.

Most of the cases encountered here of inhomogeneity late in training have occurred with a shock intensity rather near the avoidance threshold. After increasing the shock intensity, dramatic improvements have been seen in temporal discriminations along with inhomogeneity decreases.

In summary, the author's experience with rats has been that a clear discrimination has consistently been visible under the following conditions: (1) extended training, (2) R\*S no more than 30 sec, (3) shock intensity not close to the avoidance threshold, (4) data examined with the IRTs/Op statistic, (5) no serious

inhomogeneity present in the sample, (6) exclusion of the infrequent cases of primarily postshock responding. No published data is known that contradicts this statement, though unfortunately information is often lacking on (4) and (5), and there does not seem to be any published data on monkeys. Consequently, the available data agrees with the view that CATS play an important role in the reinforcement of well-trained Sidman avoidance behavior when the R\*S is no more than 30 sec.

*Temporal discriminations early in training.* Are temporal discriminations important only after extended training, or is there some sign of them early in training? Unfortunately, the literature does not provide an adequate answer at present. However, there is one interesting figure given by Sidman (1952) which is reproduced here as Fig. 10 with its original caption. This figure shows the frequencies of various time intervals between a shock and the following responses. Consequently, these data pertain to the discrimination during the S\*S interval, not the R\*S. Since S\*S was 20 sec, a shock occurred at 20 sec on the abscissa. An IRTs/Op curve could not be calculated because the number of cases of no response during the S\*S interval was not given. However, even in this raw frequency curve there is a surprisingly good discrimination present in the first session and the clear difference between medium and long IRTs would be further increased by the IRTs/Op calculation.

Study of this question has been started in this laboratory. Inhomogeneity is quite conspicuous early in training (for example, see Fig. 1 of Sidman, 1953a). The changes from one response rate to another often are too closely spaced to provide adequate samples for separate analysis. With some rats discriminations of the S\*S interval were seen in the first session (10 hr long), and the beginning of an R\*S discrimination was often seen in the first session, sometimes as early as 1½ hr after the first response. But with other rats, there was no sign of such early discrimination. There seem to be other factors in addition to the serious inhomogeneity problem that tend to obscure the early signs of discrimination.

In summary, there are important processes that obscure temporal discriminations on the first day. But the available data indicate that, at least with some animals, CATS may be

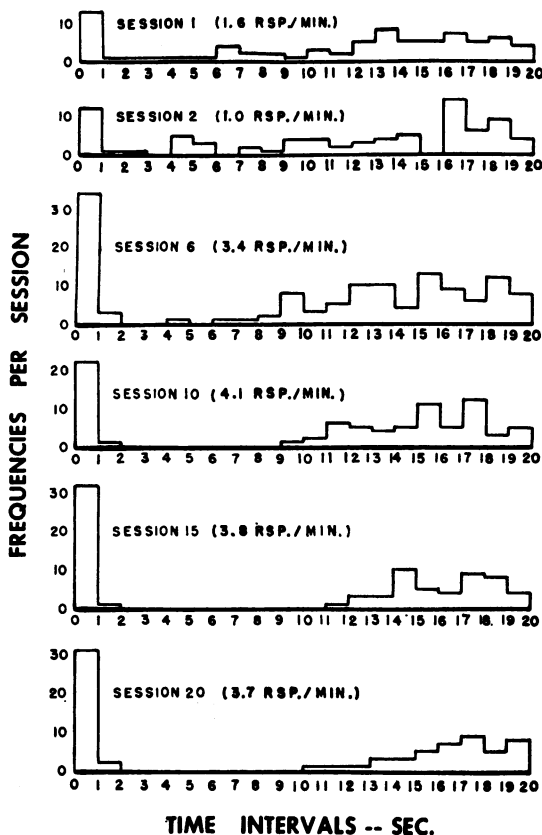


Fig. 10. A copy of Fig. 5 from Sidman (1952). The original caption read: "Frequency distributions of intervals between shocks and the first avoidance response following the shock. Distributions are presented for one animal during several three-hour conditioning sessions. The average rate of avoidance responding is given for each session."

important during the first day of conditioning as well as after extended training. Whether this is true of all animals is not known at present. Although CATS reinforcement may condition animals, it may also be that some animals lack temporal discriminations at first, and condition with CAR reinforcement. Then later, after the temporal discrimination develops, CATS reinforcement replaces the earlier CAR reinforcement.

#### STATUS OF THE CONDITIONED-AVERSIVE-TEMPORAL-STIMULI FORMULATION

The above discussion shows that the CATS formulation of the reinforcement of Sidman avoidance fits the available data. It was not practical in this paper to examine all the experimental results in this field; instead, the results that seemed to pose the most difficulties for the CATS formulation were selected. Other data are handled as adequately, although there are interesting experiments where the data are insufficient to determine just how the CATS analysis would work.

Therefore, the CATS theory seems as worthy of consideration as the CAR theory in attempts to explain various results obtained with Sidman avoidance procedures. Both theories are equally reasonable, both are based on equally well-known processes, and they differ little in the evidence for their basic assumptions. Yet the two approaches seem sufficiently different to permit experimental determination of their relative importance in different situations.

Although at present there does not seem to be any available data on Sidman avoidance or closely related procedures which the CATS formulation cannot handle, it should not be concluded that CAR reinforcement is never important. New procedures probably can be devised where CAR reinforcement is of major importance, but they can best be analyzed along with new experimental data. In ordinary Sidman avoidance procedures probably CAR reinforcement has at least some role under some conditions.

However, a stronger statement can be made about CATS reinforcement than has yet been made. There seems to be a situation where the evidence indicates the response is maintained primarily by CATS reinforcement and

CAR reinforcement is minor, namely, when an extreme temporal discrimination is present.

Consider Fig. 11 which gives the IRTs/Op curve calculated from a cumulative frequency curve used by Sidman (1954, Fig. 5) to illustrate an extreme temporal discrimination. Both R\*S and S\*S were 20 sec. There seems to be no doubt that the rat was discriminating 16- to 20-sec PRTs from 0- to 8-sec PRTs. Since the 16- to 20-sec PRTs are closely paired with shock while the 0- to 8-sec PRTs have a much more remote association, it follows that the 16- to 20-sec PRT stimuli will be more aversive than 0- to 8-sec PRT stimuli. Consequently, responding at 16- to 20-sec PRTs will be reinforced by the change from more aversive to less aversive PRTs. Given a well-developed temporal discrimination, it appears difficult to deny the conclusion that the avoidance response is being reinforced by a reduction in aversiveness due to the change from one temporal stimulus to another.

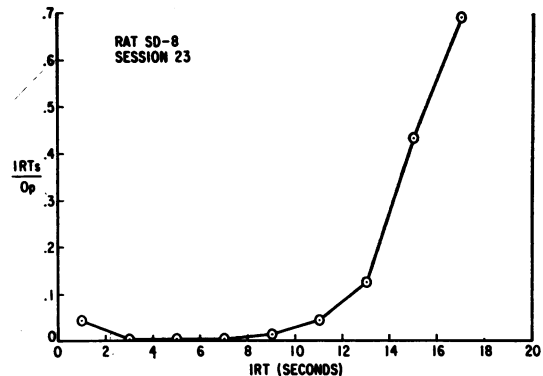


Fig. 11. A well-developed temporal discrimination. The data from Fig. 5 of Sidman (1954) were recalculated to show IRTs/Op. R\*S and S\*S were both 20 sec.

Sidman's discussion of temporal discriminations seems to agree with much of the above argument. He says: "Avoidance responses and shocks initiate 'safe periods', during which the probability of an avoidance response is relatively low." (Sidman, 1955, p. 449, cf. also 1954, p. 401). This seems to say that short PRT stimuli are not aversive and implies that not-short PRT stimuli, *i.e.*, long PRT stimuli, are aversive. It seems to follow that there will be a decrease in aversiveness following an avoidance response that will reinforce that response.

It is difficult to see how CAR can have an important reinforcing role when a discrimina-

tion develops to the degree shown in Fig. 11. During the 0- to 10-sec PRTs, the animal rarely presses the bar. If non-bar-responses are aversive during those 10 sec, it is hard to see why so few bar-responses are made to escape them. If non-bar-responses are not aversive during the first 10 sec, why do they become aversive at 16-sec PRTs? There seems to be little value in proposing that the conditioned aversive stimulus is a compound of non-bar-pressing behavior plus a temporal stimulus because the temporal stimulus would be controlling the behavior and the non-bar-pressing behavior would not be, and would make no contribution to the compound. Why propose a compound when one member does all that the compound can do?

When sharp temporal discriminations are present, a dilemma results if CATS are denied any reinforcing action. Either the temporal stimuli do or do not differ in aversiveness. If they do not, then what explanation is there for the sharp temporal discriminations? On the other hand, if temporal stimuli do differ in aversiveness, how can one deny that the avoidance response will be reinforced by the change from more aversive to less aversive temporal stimuli?

A variation on this view may clarify the issues although it is admittedly less rigorous. In Sidman avoidance, the experimenter arranges for an exact correlation between shock and a certain PRT. He does not arrange what responses will be paired with the shock, though the shock-PRT relation does arrange for no close association between shock and the avoidance response. The shock-response relation is secondary and many factors enter into determining just what responses are paired with shock and how often. Since there are many different non-bar-responses, their relative frequency would have considerable influence on their individual frequencies of correlation with shock. In short, the shock-PRT relation is a direct, exact relation; the shock-response relation is an indirect, inexact one. Sometimes it is seen from data like Fig. 11 that the rat has precisely adjusted his behavior to exactly the variable that is the best predictor of shocks, the same one the experimenter is using to program shocks. Then it is hard to believe that the relation actually controlling the behavior is not the precise one the experimenter set up and the rat is clearly react-

ing to, but instead, a different relation, one with an imprecise, fluctuating, and crude relation to the shocks that cannot explain the precise temporal discrimination. It is hard to believe that the precision time discrimination of Fig. 11 is just an epiphenomenon and that the real control of the behavior, its reinforcement, lies in a much less precise relation.

It has just been proposed that there are Sidman avoidance situations, especially those with well-developed temporal discriminations, where CATS are of considerable importance and provide most of the reinforcement for the response, and CAR play a minor or negligible role. However, it is expected that there will be demonstration of procedures where CAR are of considerable importance and may provide most of the reinforcement with CATS playing a minor or negligible role. Probably under other conditions both CATS and CAR are of some importance. There may even be differences in their relative importance in different animals in the same situation. The question does not seem to be whether Sidman avoidance is reinforced by CATS or CAR, but rather what conditions give CATS reinforcement, and what conditions give CAR.

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